THE INFLUENCE OF WEATHER ON CROP YIELDS AND FARM INCOME IN NORTHWESTERN KANSAS

by 544

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I INTRODUCTION

Justification

Weather effects are no longer regarded as random errors in crop production research. They play the same in determining crop production as do technological improvements. Favorable weather interacts with technology to produce a high yield, while bad weather might decrease yield considerably.

However, little is known about the true 'cause-and-effect' relationships between weather phenomenon and yield, and about the way in which weather elements combine to influence growth and yield. One 'growth law' hypothesis is that factors influencing growth are not simply additive, and such approach will not adequately explain the complex nature of the growth process.[1] Joint relationships among weather variables are the most difficult to explain. High temperature combined with an ample moisture supply may be beneficial to crops, but may injure them when soil moisture is insufficient.[2] In addition, the interaction between technology and weather is still not well understood. Some improved technology alone will not produce high yield without favorable weather. Probably much of the effect on yield is

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[1] Sanderson, Fred H., Methods of Crop Forecasting, Harvard University Press, Cambridge, Massachuetts, 1954, pp. 198-199.

[2] Ibid., p. 197.

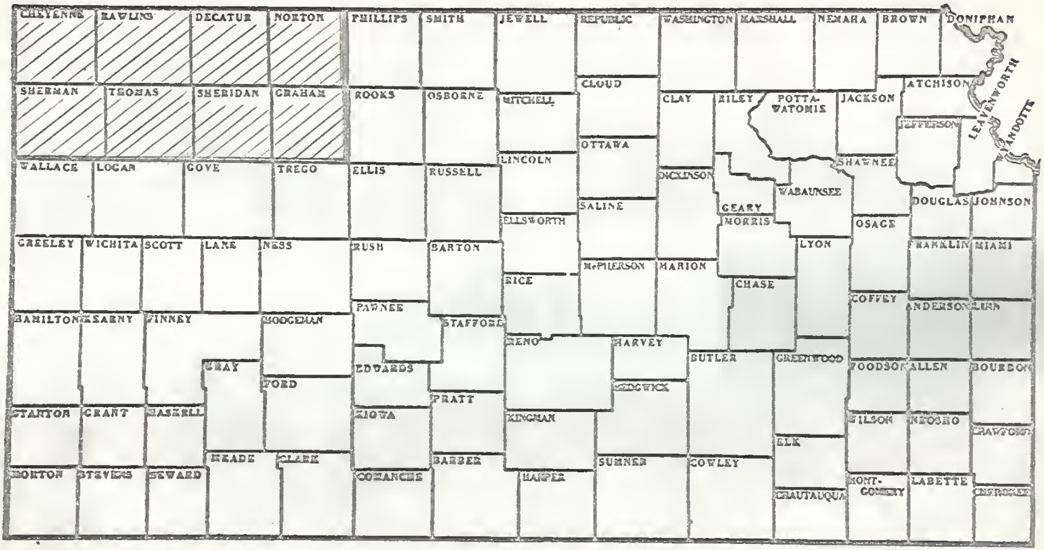

Fig. 2 Area of Northwestern Kansas

due to the interaction.[1]

Much work has been done to explore the functional relationships between weather and crop production. Also, considerable research has been devoted to finding more refined techniques to measure the effect of weather on crop production.

In this study, a multiple quadratic regression model is used to estimate the impact of weather on crop yield and on farm income from cash crops; and a recursive model is used to estimate the impact of weather on numbers and farm value of cattle reported on farms on January 1 of each year. The influence of technology on production is estimated by adjusting data for a linear trend fitting to the result of moving average and on income by including a time variable in the equation.

This study is of Northwestern Kansas which consists of eight counties: Cheyenne, Rawlins, Decatur, Norton, Sherman, Thomas, Sheridan, and Graham (Fig. 1.). This area is known for the frequent occurrence of drought.

Objective

Initial work is a review of Palmer's drought severity index[2] and of models to use in the study of weather on crop production, cattle production and on farm income. The main

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[1] Shaw, Robert H., and Thompson, Louis M., "Grain Yields and Weather Fluctuations," CAED Report 20, Center for Agricultural and Economic Development, Ames Iowa, 1964, p. 9.

[2] Palmer, Wayne C., "Meterological Drought," U.S. Weather Bureau Research Paper No. 45, Washington, D.C., Feb. 1965.

objective of this study is to estimate the influence of weather on crop yield,[1] farm income from cash crops, number and farm value of cattle reported on farms January 1 of each year. Also, the cyclical relationships between weather and agriculture is studied.

Measurement of Weather

The elements of weather and climate considered most important on crop production are (1) temperature, (2) precipitation and humidity, (3) to a lesser degree wind, and (4) air pressure. Weather refers to day-to-day state of these elements. On the other hand, climate is defined as a composite of day-to-day weather condition.[2]

Weather, here, is expressed in terms of drought severity index and monthly moisture departure as developed by Palmer. Although, he confined his remarks about agro-climatic risks to "certain aspects of the risk of a moisture shortage."[3] However, his drought severity index includes all the direct and indirect

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[1]This study is only concerned about the relations of weather to crop yield per acre, and not concerned about the relations of weather to crop supply.

[2]Trewartha, Glenn T., An Introduction to Weather and Climate, McGraw-Hill Book Co., Inc., New York, 1937, p.5.

[3]Palmer, Wayne C., "Climate Variability and Crop Production," CAED Report 20, Center for Agricultural and Economic Development, Ames, Iowa, 1964, p. 174.

effects of meterological elements which are reflected in Thornthwaite and Holzman's evapotranspiration formula[1] -- a function of four factors: climate, soil moisture supply, plant cover, and land management.[2]

Weather effects, here, include two parts: the direct effects such as those affecting plant structure, characteristic and growth rate, and the indirect effects such as favoring or checking the development of parasites and weeds relevant to weather. No attempt has been made to separate these two effects.

Following is a brief summary of the concept of drought and drought severity index as defined by Palmer.

Drought and Drought Severity Index

Definition of Drought

Drought is defined as "a prolonged and abnormal moisture deficiencies."[3] This is a meterological definition rather than a specific biologic or hydrologic. By this definition, drought severity is "a function of moisture demand as well as moisture supply,"[4] both in "duration and magnitude of the moisture

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[1]Thornthwaite, C. W., and Holzman B., "Measurement of Evaporation from Land and Water Surface," U.S. Dept. of Agriculture, Soil Conservation Service, Technical Bulletin No. 817.

[2]Oury, Bernard, "Allowing for Weather in Crop Production Model Building," Journal of Farm Economics, Vol. 47, No. 2, May, 1965, p. 272.

[3]Palmer, "Climate Variability and Crop Production," op.cit., p. 179.

[4]Ibid., p. 179.

deficiency."[1] Also, it depends on "the climate itself because drought is a relative condition."[2]

Definition of Drought Period

A drought period is an interval of time during which "the actual moisture supply at a given place rather consistently falls short of the climatically expected or climatically appropriate moisture supply."[3]

Components of Drought Severity Index

Several elements have been included in computing the drought severity index. The main factors involved are: (1) the climatic characteristic which is a function of long-term mean potential evapotranspiration, long-term mean soil moisture recharge, long-term mean soil loss, and long-term mean precipitation; and (2) the difference between area average precipitation and CAFEC[4] (Climatically Appropriate For Existing Condition) precipitation. CAFEC precipitation is a composite of CAFEC evapotranspiration, CAFEC soil moisture recharge, CAFEC runoff and CAFEC soil loss.[5] Previous month's weather condition, duration

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[1]Palmer, "Meterological Drought," *op. cit.*, p. 3.

[2]Palmer, "Climate Variability and Crop Production," *op. cit.*, p. 179.

[3]Palmer, "Meterological Drought," *op. cit.*, p. 3.

[4]That is, the various computed CAFEC amounts of precipitation, evapotransporation, recharge, etc., are ones which should be climatically appropriate for the conditions of the time and place being examined. *Ibid.*, pp. 12-13.

[5]*Ibid.*, pp. 9-27.

of drought and other adjusting factors are taken into account. One of the features of this index is that it permits "time and space comparisons of drought severity,"[1] as soil condition and time have been considered in computation.

Classification of Severity Index

The drought severity index is set up and assigned descriptive names as shown in Table 1. Drought severity index of zero is used as "normal" weather.[2] During extreme drought with drought severity index less than -4.00, crop yields are ordinarily expected to be near zero or so low as to be unprofitable.[3]

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[1] Ibid., p. 1.

[2] Ibid., p. 28.

[3] Palmer, Wayne C., "Climatic Variability and Crop Production," CAED Report 20, Ames, Iowa, 1964, p. 180.

TABLE 1. -- Classification of drought severity index[a]

Drought Index		Severity	Class
	>	4.99	Extreme wet
3.00	to	3.99	Very wet
2.00	to	2.99	Moderately wet
1.00	to	1.99	Slightly wet
0.50	to	0.99	Incipient wet spell
0.49	to	-0.49	Near normal
-0.50	to	-0.99	Insipient drought
-1.00	to	-1.99	Mild drought
-2.00	to	-2.99	Moderate drought
-3.00	to	-3.99	Severe drought
	<	-4.99	Extreme drought

[a]Source: Palmer, Wayne C., "Meterological Drought," U.S. Weather Bureau Research Paper No. 45, Washington, D.C., Feb., 1965, p. 28.

II REVIEW OF LITERATURE

Measurement of Meteorological Variables

Early studies of the impact of weather on crops used separate weather factors such as average rainfall and temperatures during June, July and August[1] or mean maximum daily temperature and mean daily rainfall during retting period as indicators of meteorological phenomena. This approach recognizes the role of weather in crop production.[2] Such an approach does not include the month to month variation in weather[3] and also overlooks the fact that yield is determined by "a continuous function in time of the growth factors."[4] Besides, temperature and rainfall themselves do not completely indentify weather. Other variables should also be included.

Several other measurements of weather phenomena have been suggested in order to investigate the weather effect on crop production. Dale[5] applied 'moisture stress day', given by

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[1]For example see Ezekiel, M., and Fox, Karl A., Methods of Correlation and Regression Analysis, New York, John Wiley & Sons, Inc., 1965, p.212. Original source: Misner, E.G., "Studies of the Relation of Weather to the Production and Price of Farm Products, I. Corn," Mimeographed Publication, Cornel University, Mar., 1928.

[2]For example see Williams, E. J., Regression Analysis, New York, John Wiley & Sons, Inc., 1959, p. 26.

[3]Thompson, Louis M., "Multiple Regression Techniques in the Evaluation of Weather and Technology in Crop Production," CAED Report 20, Ames, Iowa, 1964, pp. 86-89.

[4]Sanderson, op. cit., p. 200.

[5]Dale, Robert F., "Change in Moisture Stress Days Since 1933," CAED Report 20, Ames, Iowa, 1964, pp. 23-43.

Denmead and Shaw[1], in a study of the relationship between weather and corn yield. Blake applied Penman's formula as a measure of moisture excesses.[2] Oury used a composite 'aridity' index based on de Martonne's and Ångströn formula[3], however, the construction of this index is also based on precipitation and temperature. Most of the measurements of weather are related to the concept of evapotranspiration.

Weather-Crop Functional Studies

Published studies show that several alternative methods have been used to study the relationships between weather and crop production. According to their objectives, these studies can be classified into two categories:

(1) Attempt to measure quantitatively the impact of weather on crop production with weather as variables. A few attempts have also been made to investigate the interaction between weather and technology and to forecast crop production. This is essentially a study of the functional relationships between crop and weather.

(2) Establish a weather index for economic analysis. Two approaches have been suggested: (a) Weather can be measured by

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[1]Denmead, O. T., and Shaw, R. H., "Availability of Soil Water to Plants as Affected by Soil Moisture Content and Meterological Conditions," Agronomy Journal, Vol. 54, No.5, pp. 385-390.

[2]Blake, G. R., et at, "Agricultural Drought and Moisture Excesses in Minnesota," University of Minnesota Agricultural Experiment Station, Technical Bulletin 235, May 1960.

[3]For detail discussion see Oury, Bernard, op.cit., pp.270-283.

direct meteorological observation, such as temperature, rainfall, etc. The index constructed by Oury is also based on this concept; (b) Measure weather by its secondary effects, such as the percentage of abandoned acres, the incidence of a disease, the deviation from the computed trend, such as the Stalling's approach.

Some economists are not satisfied with the weather measurement developed by climatogists, agronomist and other technical scientists for economic analysis because "the functional relationship between these variables and yield is not known."[1] Therefore, another alternative measure of weather has been established. This method treats the deviation from the trend as the weather effects which is the so called 'stalling approach'.[2] A little modification of this procedure was used by Shaw and Durost.[3] However, Wallace was the first to recommend this approach.[4]

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[1]Doll, John P., "An Analytical Technique for Estimating Weather Indexes from Meterological Measurements," Journal of Farm Economics, Vol. 49, No. 1, Feb. 1967, p. 81.

[2]Stalling, James L., "Weather Indexes" Journal of Farm Economics, Vol. XLII, Feb. 1960, pp. 180-186. Original report is his unpublished Ph. D. thesis, "The Influence of Weather on Agricultural Output," Michigan State University, 1954.

[3]Shaw, Lawrence H. and Durost, Donald D., "Measuring the Effects of Weather on Agricultural Output," Economic Research Service, Dept. of Agriculture, Washington, D.C., 1966.

[4]Ibid., p. 2.

Statistical Techniques

Regression Equation Model

Linear regression analysis was used by some early researchers. One of the deficiencies in this approach is that it does not explain the phenomena of decreasing production due to extreme weather condition -- too dry or too wet. To correct this shortcoming, Ezekiel applied multiple curvilinear regression to crop studies.[1] Thompson also used the same approach to the study of grain sorghum[2], corn and soybean[3] by using monthly rainfall and temperature data as weather variables. Their results showed a satisfactory R^2.

Estimation of Technological Improvements

Trend Removed and Trend Involved

Applying regression analysis to time series yield data involves estimating increase in yield due to technology. Two different methods have been suggested to estimate it: trend removed and trend involved. The former is with trend removed before the regression analysis; the later treats time as an

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[1] Ezekiel, M., Methods of Correlation Analysis, Second edition, John Wiley & Sons, N. Y., 1941, Chap. 21.

[2] Thompson, Louis M., "Evaluation of Weather Factors in the Production of Grain Sorghums," Agronomy Journal, Vol. 55, No. 2, 1963.

[3] Thompson, Louis M., "Weather and Technology in the Production of Corn and Soybeans," CAED Report 17, Ames, Iowa, 1963.

independent variable in the equation.

Yule is in favor of trend removed. His main argument is that "trends (i.e. treating time variable as an independent variable) may give rise to spurious correlation and spurious regression."[1] It has been shown that including a time variable with other variables in the equation will cause unduly high correlation.[2]

An alternative approach in dealing with trend is to directly involve a time variable in the equation.[3] The main argument against trend removal is that it might throw away some of the statistical information.

The choice between trend removal and treating a time variable as an independent variable is based on data characteristics and the properties of the independent variables being selected.

Moving Average and Least Squares Method

Fluctuation in the time series data, Y (t), may be regarded as a composite of secular trend, T (t), seasonal variation, S (t), cyclical movement, C (t), and irregular fluctuation, I (t).

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[1]Wold, Herman and Juréen, Lars, Demand Analysis, John Wiley & Sons, Inc., New York, 1966, p. 240.

[2]Foote, Richard J., "Analytical Tools for Studying Demand and Price Structures," Agricultural Handbook No. 146, U.S. Dept. of Agriculture, Aug., 1958, p. 32.

[3]Ibid., pp. 39-42.

This statement is expressed as follows:

$$(2\text{-}1) \quad Y(t) = T(t) + S(t) + C(t) + I(t)$$

Therefore, secular trend is determined by subtracting seasonal, cyclical and irregular variation from time series, i.e.

$$(2\text{-}2) \quad T(t) = Y(t) - S(t) - C(t) - I(t)$$

Several approaches might be used in removing trend. Of these, the two most commonly used are the moving average and the least squares method. Each has its unique properities. The choice of the method largely depends on whether or not a cycle exists.

Stalling removed trend by the least squares approach.[1] Shaw and Durost rejected this approach giving the reason that "weather cycle, should they exist, might possibly introduce error into this trend procedure."[2] They used a new approach: fitting a linear trend by the least squares method to the results of the nine-year moving average.

When time series is clearly not linear and reveals a cycle, it is customary to study the smoothing behavior of a

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[1]Stalling, "A Measure of the Influence of Weather on Crop Production," op. cit., p. 1159.

[2]Shaw and Durost, op. cit., p. 11.

moving average.[1] But this method has several shortcomings: first, it loses the data of the ends and it cannot be extrapolated; second, it is possible to introduce artificial oscillation due solely to the selection of length of the moving average especially when the time series exhibits regular fluctuation. This is the so called 'Slutzky' effect.[2] These two deficiencies might be overcome by using least squares to fit a trend to the moving average.

Estimating Technological Improvements

Trend computed from data only provides a crude approximation of, but not a precise measure of, the technological improvements.[3] When the trend is estimated by least squares while omitting factors such as weather variables and the interaction between technology and weather, the estimated regression coefficient will be different from the true value if these independent variables are correlated.[4]

The reasonable conclusion may be that we should make some allowances in using the computed trend as the actual trend and/or the technological improvements.

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[1]Chou, Ya-lun, Application Business and Economic Statistics, Halt, Rinehart and Winston, 1963, pp. 517-520.

[2]Slutzky, Eugen, "The Summation of Random Causes as the Source of Cyclic Processes," Vol. 5, Econometrica, 1937, pp. 105-146.

[3]For discussions in detail see Appendix B.

[4]Christ, Carl F., Econometric Models and Methods, John Wiley & Sons, Inc., New York, 1966, pp. 388-389.

III DATA

Source and Characteristics of Data

In the study of the effect of weather on crop yield and farm income from cash crops, data for the period from 1932 to 1965 are used. This period is selected for study for two reasons: (1) drought severity index data is available only for a limited period, 1930-1965; (2) this period reveals nearly two cycles. However, in the study of the effect of weather on production and farm value of cattle, only the period from 1943 to 1965 is considered. To use the data of the early period in regard to feed production, several adjustments are necessary to make it comparable with data for the later period. These adjustments are believed to introduce more error than does the elimination of this time period. Therefore, the data for feed production of early years has been omitted.[1]

The following section is a general description of the data used in this study. Some data are from primary sources, and some are calculated from primary sources. Mean and variance are used to show the level and the dispersion of these variables.

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[1] In the study of T.D.N. yield (tons per acre) as a function of weather based on 1932-1965 data, the R^2 is 0.56 and the standard error is 0.24. If 1943-1965 data are used, however, the R^2 is 0.89 and the standard error is 0.098. This large difference is thought to be due to the adjustment error in the 1932-1944 data.

Crop Yield and Livestock Estimates

Reported crop yields (bu. per acre) for the northwest Kansas reporting district are taken from Farm Facts.[1] Wheat includes spring wheat and winter wheat (Table 26 of Appendix A); grain sorghum is an aggregate of various types and varieties. In the period 1932 to 1936, it is composed of milo, kafir, and feterila, while in the period 1936 to 1965, it is just grain sorghum. (Table 27 of Appendix A). Corn is a combination of hybrid and cross-pollinated types.

The mean and variance of the crop yields (bu. per acre) for wheat, corn and grain sorghum from 1932 to 1965 are presented in Table 2. Time series, moving average, and the linear trend computed from the moving average of these crop yields are depicted in Fig. 2. Fig. 3 shows the fluctuation of these crop yields with trend removed, and indicates that the phase and amplitude of the fluctuation in wheat, corn, and grain has a very similar pattern. Also, the fluctuation of crop yields with trend removed (Fig. 3) is consistent with the fluctuation of the drought severity index (Fig. 5).

Forage and silage are used as estimates of feed production. Pasture is not considered because data concerning pasture production is not available. But, it is assumed that it is highly correlated with forage and silage production. Total production

[1] Kansas State Board of Agriculture, Farm Facts, Topeka, Kansas, 1930-1965.

TABLE 2. -- Mean and variance of variables, in weather and cash crops studies, Northwestern Kansas, 1932-1965.[a]

Items	Mean	Variance	Items	Mean	Variance
Wheat[a]	-0.32	28.37	Farm Income (mil. $)	34.98	530,755,900.00
Corn	-0.53	40.14	Aggregate Price Index	2.28	0.72
Grain Sorghum	0.09	38.95	Trend	17.50	99.17
Drought Severity Index of			Monthly Moisture Departure of		
$Oct._{t-1}$	-0.18	11.99	$Oct._{t-1}$	0.01	1.81
April	-0.15	7.31	April	-0.14	2.58
June	-0.01	9.11	June	0.23	6.33
August	0.15	13.44	August	0.04	2.86
October	-0.05	2.89	October	0.10	2.07

[a]Yield of wheat, corn, and grain sorghum are bu./acre in dry land, trend has removed, i.e., Y - Y' where Y' = A + BT.

of forage and silage are converted into total digestible nutrients (T.D.N.) to provide a common basis for aggregating, and are weighted on the basis of 0.455(ton/acre) for forage and and 0.152(ton/acre) for silage.[1] Total T.D.N. produced divided by total harvested acres gives the average T.D.N. per acre used in the estimating equation. The data for forage, silage, and T.D.N. are listed in Table 31 and Table 33 of Appendix A; variance and means in Table 3 and time series in Fig. 4. Total adjusted harvested acres (Table 33) is the sum of harvest acres of forage plus weighted harvest acres of silage. One acre of silage is considered equal to 0.334 acre of forage in producing the same amount of T.D.N.[2] This weighting procedure is necessary because the amount T.D.N. produced on an acre of forage is approximately one-third that produced from an acre of silage.

Total numbers of all cattle except milk cows on hand, on January 1 of each year, as reported in Farm Facts, are used in the estimate of the number of cattle in the study of the effects of weather on livestock production. Production of

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[1] T.D.N. for forage (45.5%) is based on an average of reported T.D.N. for several crops, including milo stover, kafir stover and corn stover. T.D.N. for silage (15.2%) is based on reported T.D.N. for sweet sorghum silage. See Morrison, F.B., Feeds and Feeding, Morrison Publishing Co., Ithaca, N.Y., 21ed., 1954.

[2] Since each ton of forage is equal to 0.455 tons T.D.N., and each ton of silage is equal to 0.152 tons T.D.N., one harvest acre of silage is only 0.334 acres (0.152/0.455 = 0.334) of forage in producing the same amount of T.D.N.

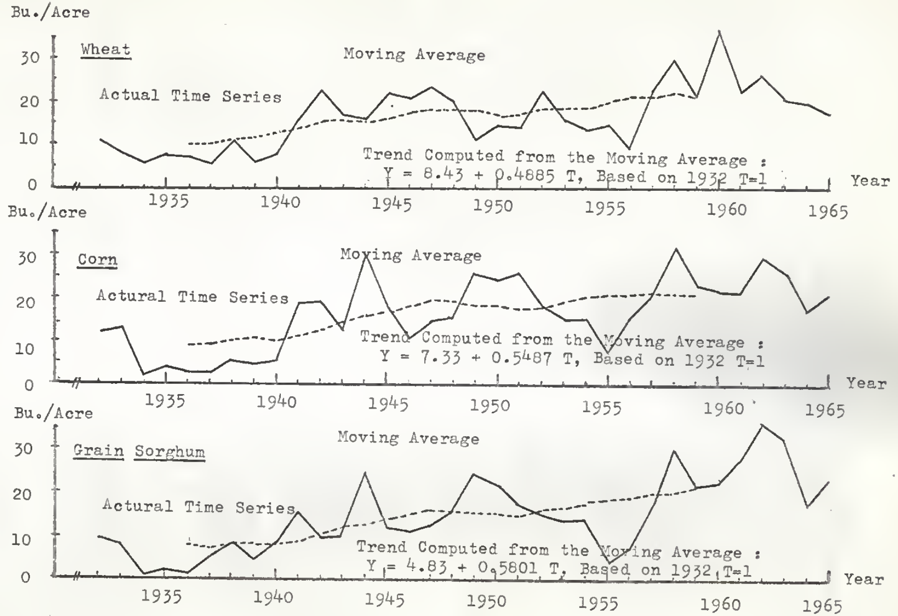

Fig. 2 Fluctuation, moving average, and trend of yield (dry land) in wheat, corn, and grain sorghum, Northwestern Kansas, 1932-1965.

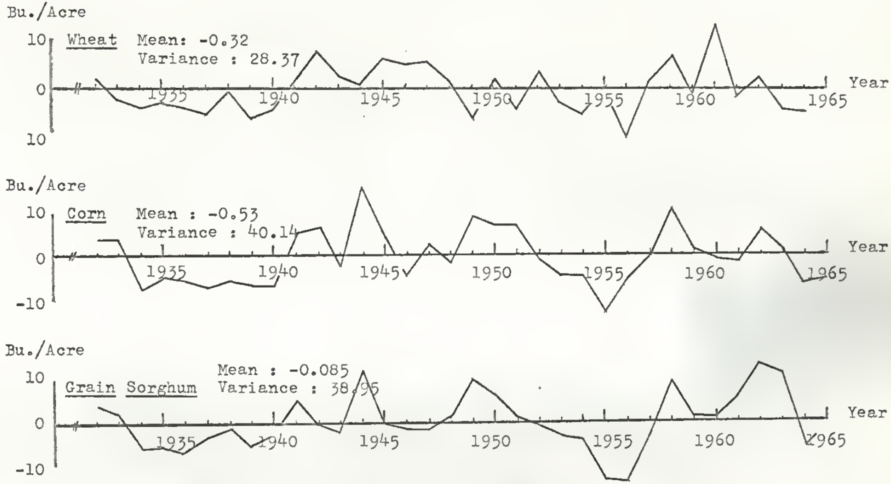

Fig. 3 Yield variation as deviation from trend in wheat, corn, and grain sorghum, Northwestern Kansas, 1932-1965.

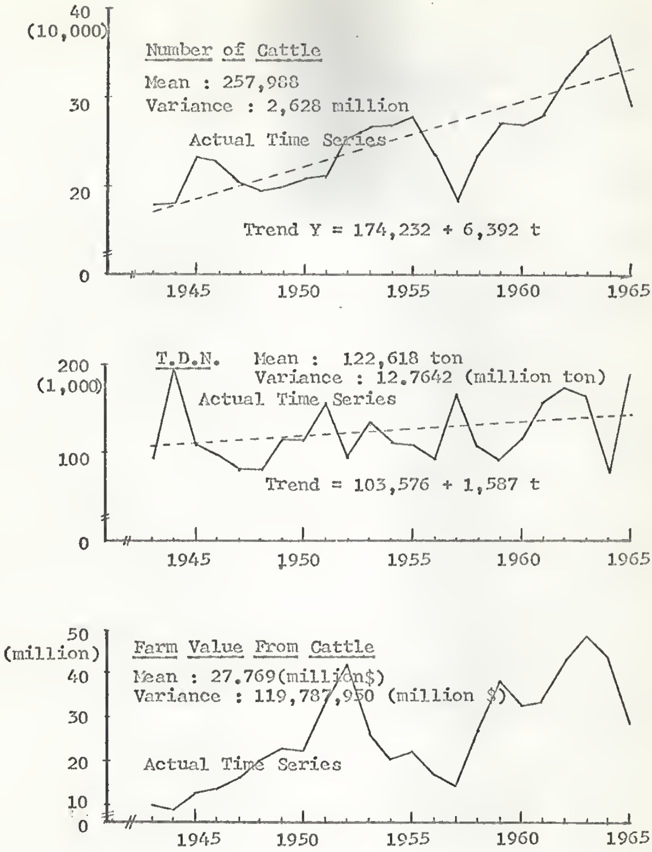

Fig. 4 Fluctuations and trend in number of cattle, T.D.N., and farm value of cattle, Northwestern Kansas, 1943-1965.

milk cows, sheep, horses and all poultry are not considered in this study for the following two reasons: (1) their value constituted only a small fraction of the value of total livestock in the early period, and (2) these various types of livestock are difficult to aggregate in terms of cattle.

TABLE 3. -- Mean and variance of variables in weather-cattle studies, Northwestern Kansas, 1943-1965.

Items	Mean	Variance
Farm Value of Cattle [a] (million $)	27.769	119,787,950
Reported Number of Cattle	257,988	2,628,300,000
No. of Estimated Cattle	257,987	2,082,615,000
Reported Average T.D.N. (ton/acre)	0.782	0.070
Estimated Average T.D.N. (ton/acre)	0.773	0.060
Price Index of Cattle	1.850	0.288
Price Index of T.D.N.	1.171	0.112
Price Ratio	1.523	0.255
Trend	11.000	38.500

[a]Cattle excludes milk cows.

Farm Income and Price Estimates

Farm income from cash crops data is the aggregate farm value of the main cash crops, wheat, corn, and grain sorghum, as reported in Farm Facts. Income from irrigated production is excluded. Primary data is collected by the Statistical Reporting Service of the U.S. Department of Agriculture, and reported in Farm Facts.

Total value of all cattle except milk cows on hand on January 1 of each year as reported in Farm Facts is used in the estimate of the effects of weather on farm value of cattle. It is considered that the value of cattle on hand on January 1 of each year is closely associated with the farm income from livestock in that year.

The price for each crop is computed from reported farm value divided by total reported production. Results and computational procedures are included in col. 5, 6, and 7, of Tables 26, 27, and 28 of Appendix A.

The aggregated price index is calculated using Laspeyre's formula,[1] $\frac{\sum P_i Q_o}{\sum P_o Q_o}$, where P_o and Q_o are the prices and quantities of a specific crop based on 1930, and P_i is the price of the same crop but in the ith year. Wheat, corn, and grain sorghum are included in the construction of the price index. Table 4 illustrates the computation of the aggregated

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[1]Mills, Frederick G., Statistical Methods, Henry Holt and Company, New York, 1955, p. 450.

price index for 1965.

TABLE 4. -- Computation of aggregated price index for 1965[a]

Items	Wheat	Corn	Grain Sorghum
Price in 1965	1.2899	1.1903	0.9300
Price in 1930	0.5765	0.5467	0.6447
Prod. in 1930	22,397,825(bu.)	17,166,972(bu.)	471,260(bu.)

[a]Data are selected from Tables 26, 27, and 28 of Appendix A.

Therefore, the aggregated price index for 1965 is

$$\frac{(1.2899)\times(22,397,825) + (1.1903)\times(17,166,972) + (0.9300)\times(471,260)}{(0.5765)\times(22,397,825) + (0.5467)\times(17,166,972) + (0.6447)\times(471,260)}$$

$= 2.2017$

The price index for 1930-1965 is presented in col. 4, Table 30, Appendix A. The price index of cattle and T.D.N. is also constructed using Laspeyre's formula, but with base year 1943. Price ratio used is computed by dividing the price index for cattle by the price index of T.D.N.

Weather Variable

The Drought Severity Index (D.S.I.) and Monthly Moisture Departure are compiled by the state Climatologist[1] , and are

[1]State Climatologist, ESSA-Weather Bureau, Kansas State Manhattan, Kansas, 1930-1965.

presented in Tables 24 and 25 of Appendix A. These values are calculated for specific locations for each day and then aggregated for the crop reporting districts as well as for long periods of time, on a weekly or monthly basis. The values of June, August, and October are given in Figs. 5 and 6.

Data Adjustments

Several adjustments are necessary before fitting trend to dry land yields. These include eliminating the effect of irrigation on corn and grain sorghum yield, and adjusting for acres harvested on dry land.

Eliminating the Effects of Irrigation

Only dry land yield is considered in crop studies, as irrigation greatly increases yield per acre. Also, weather is believed to have much less affect on irrigated crop yields. The difference in yield between dry land and irrigated production is given in Table 5. Considering the percentage of irrigated acres (and production) of total acres (and total production), there is a large difference between 1958 and 1964 as shown in Table 6. (However, irrigation in wheat is less important.) Therefore, if irrigation effects are not eliminated, the trend after 1950 might be slightly steeper

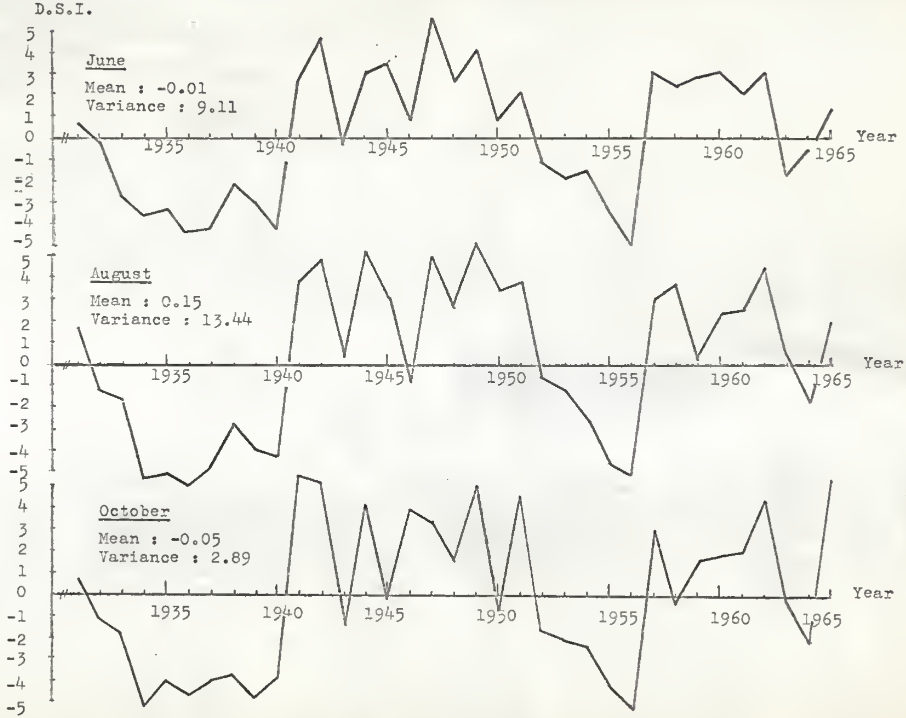

Fig. 5 Fluctuation of drought severity index in June, August, and October, Northwestern Kansas, 1932-1965.

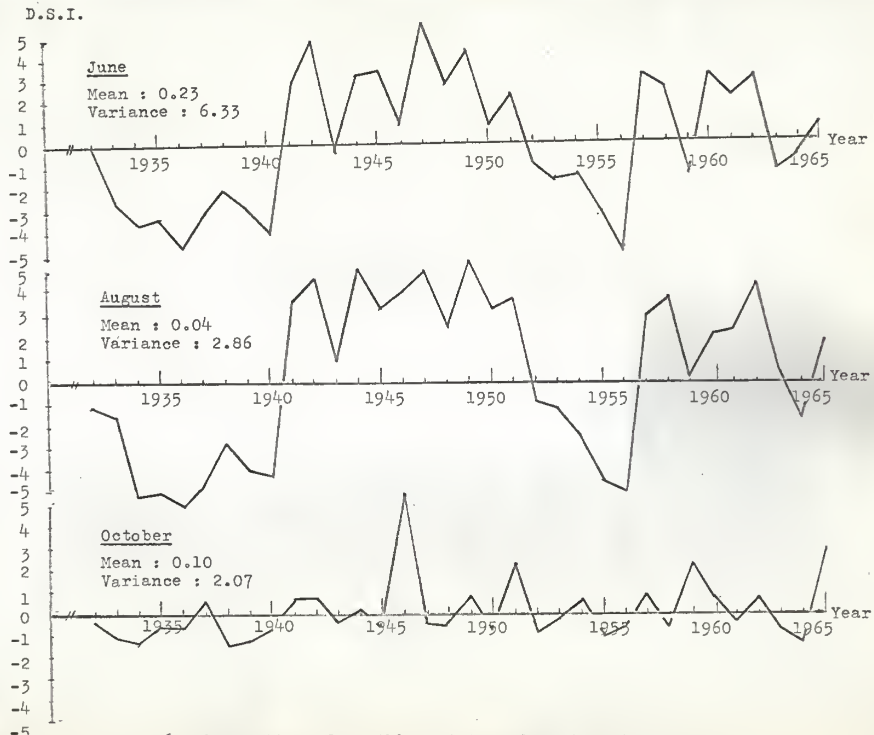

Fig. 6 Fluctuation of monthly moisture departure in June, August, and October, Northwestern Kansas, 1932-1965.

than the trend before 1950.[1] The following proeedure for the elimination of irrigation effects does permit a linear trend to represent teehnological improvements since 1930.

TABLE 5. -- Dry land yield per acre as a percentage of irrigated yield per aere, for corn, Northwestern Kansas, 1958-1964[a]

Year	Percent (%)
1964	21.29
1963	31.76
1962	33.62
1961	29.31
1960	28.78
1959	33.06
1958	47.81

[a]Computed from primary data eontained in Table 27.

Data on irrigation are available only from 1959 to 1965. For earlier years, the following procedure is used to eliminate the effect of irrigation on erop yield. 'Pooled yield' per aere is computed by dividing the total production on irrigated and dry land by total aeres harvested. 'Dry land' yield per aere is computed by dividing produetion on dry land by the number of dry land aeres harvested. In the case where

[1]Mordecai Ezekiel suggests that using two linear trends can represent different stage in teehnologieal improvement. See Thompson, "Weather and Teehnology in the Production of Corn and Soybeans," _op. eit._, p. 5.

TABLE 6. -- Percentage of irrigated acres in total acres, and percentage of irrigated production in total production, Northwestern Kansas, 1957-1965.

	Wheat		Corn		Grain Sorghum	
Year	% Irri. Prod.in Total	% Irri. Acres in Total	% Irri. Prod.in Total	% Irri. Acres in Total	% Irri. Prod.in Total	% Irri. Acres in Total
1965	1.29	0.76	-	-	33.63	13.76
1964	-	0.54	86.09	56.86	-	-
1963	0.80	0.66	59.64	31.90	9.32	4.51
1962	0.60	0.54	58.47	32.13	11.35	5.58
1961	0.34	0.32	61.71	32.09	11.30	5.17
1960	0.88	0.78	34.87	13.35	11.52	4.14
1959	0.60	0.48	23.27	9.12	11.03	4.14
1958	0.37	0.34	13.84	7.05	-	-
1957	0.10	0.10	-	-	-	-

there is no irrigation, the 'pooled yield' is identical to the 'dry land' yield. On the other hand, as more acres are irrigated, the difference between 'pooled yield' and 'dry land' yield will tend to be larger. Since there is an upward trend in number of acres irrigated from 1959 to 1965, there will also exist an upward trend in the difference between the 'pooled yield' and the 'dry land' yield over this period. This trend, calculated from the difference between the 'pooled yield' and the 'dry land' yield, is extrapolated to years prior to 1959, and thus, yield per acre is adjusted for the irrigation effect for years prior to 1959. The following computational procedure is used. (See also Table 29, Appendix A)

1) Compute the difference between 'pooled yield' (col. 2, Table 29) and 'dry land' yield (col. 3) for the period 1959-1965. The results are given in col. 4. (Table 29, Appendix A)

2) Fit a linear trend to this difference. (col. 4, Table 29)

3) Extrapolate the trend based on data from 1959-1965 for the years prior to 1959 until the estimated value approaches zero. The resulting estimate in that irrigation has little effect on reported yield per acre prior to 1950. The estimated values are given in col. 4, Table 29 with asterisk.

4) Substracting the value in col. 4 from col. 2 ('pooled yield') gives the adjusted yield for dry land. The results are given in col. 5, Table 29.

Nonweather Effect

A large portion of land was abandoned during some years (Table 7). However, not all of the abandonment can be attributed to bad weather, as part was a result of government policy and price level. To avoid the error of attributing all abandoned acres to weather, crop yield per acre is calculated using acres harvested.[1,2] Also, data on acres planted are

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[1]Conversely, Sanderson indicates that "Yield should be expressed in per acre planted rather than harvested." Sanderson, op. cit., p. 195.

[2]However, to estimate crop yield on the basis of per acres harvested rather than per acres planted would ignore the weather effect in the planting season, as some of the abandoned acres are abandoned during the planting and growing seasons.

not available for all crops studied. The best estimate of the influence of weather on yield per acre would probably be based on yield per acre of allotment.

TABLE 7. -- Abandonment acres as a percentage of acres sown for corn, Northwestern Kansas, 1937-1960

Year	%	Year	%
1960	49.22	1948	1.67
1959	8.02	1947	5.25
1958	2.61	1946	11.70
1957	2.02	1945	2.01
1956	38.77	1944	4.29
1955	49.22	1943	7.21
1954	4.86	1942	2.51
1953	5.35	1941	3.98
1952	4.89	1940	40.97
1951	4.83	1939	55.42
1950	4.17	1938	29.07
1949	1.94	1937	48.79

No data on corn acres harvested were reported during 1930-1936, and therefore have to be estimated (Table 8).

TABLE 8. -- Computational procedures for adjustment of acres harvested of corn

Year (1)	Acres Sown (2)	Acres Harvest (3)	Total Prod. (bu.) (4)	Yield based on acres sown (4) / (2) (5)	Yield based on acres har. (4) / (3) (6)	Harvest acres as percent of acres sown (3) / (2) (7)
1939	303,500	135,500	669,340	2.21	4.94	44.65(%)
1938	285,100	202,200	1,072,810	3.76	5.31	70.92
1937	440,400	225,500	689,000	1.56	3.06	51.20
1936	749,516	-	1,552,545	2.07	(to be	estimated)

Yield on harvested acres in 1936 is estimated as follows which is based on a teehnique of interpolation.

1) Seleet years when yield (based on acres sown, col. 5) is approximately 2.07 bu./acre, whieh is the yield based on acre sown for 1936. These years are 1937, 1938, and 1939.

2) the average of col. 7 in these three years is (44.65+70.92+51.20)/3 = 55.59%

3) The estimated pereentage of acres sown of harvested acres is 55.59% for 1936. So the estimated acres harvested in 1936 is 749,516 (acre) x 55.59% = 416,656 acres.

4) The estimated yield based on harvested aeres is: 1,552,545 bu./416,656 = 3.67 bu. per aere.

The estimated yield on harvested aeres for 1930-1935 are obtained using the same procedure. The results are given in cols. 3 and 4 with asterisk in Table 27.

Data on grain sorghum production are not available for 1934 and 1936 on aecount of extremely dry, and hot weather. To eliminate irregular effects from the moving average, the yield for 1934 and 1936 are adjusted and assigned 1 bu. per acre for these two years.[1] This does not eliminate the irregular fluctuation entirely, however.

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[1] One bushel per aere assigned for the yirld of 1934 and 1936 is regarded as the least yield in grain sorghum in the period of 1930-1965.

Exclusion of Technological Effects

Technology includes several factors, such as cultural practise, mechanization, application of fertilizer, use of irrigation, introduction of improved varieties, new ways of marketing and so on. These factors will cause an increase in outputs with the same set of inputs, or will maintain the same level of outputs with a lesser amount of inputs. Since the data concerning technological improvements is not available, two different means are used to estimate it, by trend removed, and treating the time variable as an independent variable. For the discussion of trend removed procedures see p. 37.

VI MODEL FORMULATION

"Economic theory proper, indeed, is nothing more than a system of logical relations between certain sets of assumptions and the conclusions derived from them."[1] Production analysis, too, is a statistical estimation and economic interpretation based on the assumption and on the model specification. Of course, the selection of a set of postulates should be supported by economic theory, mathematical consistency and other relevant sciences.

Two different kinds of models are used in this study: a quadratic multiple regression model for the study of the impact of weather on crop yield and farm income from cash crops, and a recursive model for the study of the impact of weather on number and reported farm value on January 1 of cattle.

In this chapter, the properties of the statistical techniques used in this study are first discussed; the construction of the models is discussed next; and finally, the basis for selecting the independent variables is further explained in detail.

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[1]Vickrey, William S., Microstatics, Harcourt, Brace & World Inc., New York, 1964, p.5.

Statistical Techniques

Quadratic Multiple Regression

Quadratic Form

The linear regression equation might give a less satisfactory fit due to improper mathematical form. To make the equation curvilinear and reflect a reasonable relationship, the quadratic equation is introduced. The equation implies that as weather condition deviates from the normal, the rate at which yield decreases or increases is not constant as estimated by the effect of the squares term.

Multiple Regression

A single independent variable is inadequate to explain the effect of weather variables during the entire growth season. To take account of the effects of weather at different stages of growth, drought severity indices for several months are used. However, to avoid having too many variables in the equation which might cause regression coefficients to be less significant and less reliable, only three months are selected to represent the growing season: one for planting, another for heading, and the third for harvesting.

Recursive Model

The relationships between weather, feed yield per acre, numbers and reported farm value of cattle are thought to

constitute a causal chain. Therefore, a recursive model is used.[1] The estimated value of the endogenous variable[2] in the first equation is used to estimate the second endogenous variable in the second equation, and so on. The properties of recursive model will be discussed in detail on pp. 4 - 4

Trend Included and Trend Removed

To treat trend as an independent variable in this study is to assign 1 for the base year, 2 for the second year and so on as a measure of the growth rate of technological improvements.

Trend removed used in this study is very similar to the one used by Shaw and Durost: fitting a linear trend to the moving average. Selecting the length of a moving period is entirely based on data properties. Through testing and the observation of Fig. 3, a 13-year moving average is used. The computational procedures and the results are presented in Table 29, Appendix A. The series of moving average are depicted in Fig. 2. It is obvious from Fig. 2 that a linear trend gives a good fit to the moving average.

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[1]Malinvaud, E., Statistical Methods of Econometrics, Translated by Mrs. A. Silvey, Rand McNally & Co., 1966, pp. 59-61, 512, 540-543.

[2]For the reasons of using estimated value rather than actual value see Foote, op. cit., p. 64.

Model Formulation

Quadratic Multiple Regression Function for the Study of Weather Impact on Crop Yield

Statement of Problem

Population growth, government policy, lag output, market situation, price level, acreage, technology and weather are jointly responsible for determining crop supply. In a study of supply, all of these factors should be considered.

Primary objective is to study how acreage, technology and weather affect yield and farm income from cash crops once producers have made their decision to plant. Government policy and price level are regarded as the factors affecting decision making, but these two variables are excluded from the present study. The interaction between technology and weather is not studied.

Assumption of Weather Cycle and Technology

It is assumed that weather variables for any one year are random with a normal distribution and with an expected value of zero. It is also assumed that a weather cycle exists and can be determined. It is further estimated that technological improvements show a linear upward tendency as time elapses. Then technological effects can be estimated by a fitting linear trend,[1] where trend is computed from the moving average.

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[1] For computational procedures see Table 29, and for digression discussions see Appendix B.

$$(4\text{-}1) \qquad Y' = A + BT$$

Where Y' is the estimated technological effects and T is time variable.

It is further assumed that weather and technological improvements are independent, and so no interaction effect between these two variables is considered. The deviation in yield from the trend can be regarded as the first approximated weather effect. This first approximation of weather effect, Y_W, includes all the direct and indirect weather effects, and effects of all other factors.

Simplified Model

From Fig. 7, the model can be reduced as follows:

(4-2) Crop Production = f(Weather, Technology, Acreage)

If crop production is adjusted by acres harvested, equation (4-2) can be rewritten as:

(4-3) Crop Yield (bu. per acre), Y, = f(Weather, Technology)

From equation (4-2) and (4-3), the equation of yield variation accounted for weather is:

$$(4\text{-}4) \qquad Y - Y' = Y_W = f(\text{Weather})$$

Where, Y is crop yield (bu. per acre) in dry land;

Y' is the estimated technological Improvements from equation (4-1);

Y - Y' is defined as the yield variation (bu. per acre) accounted for weather.

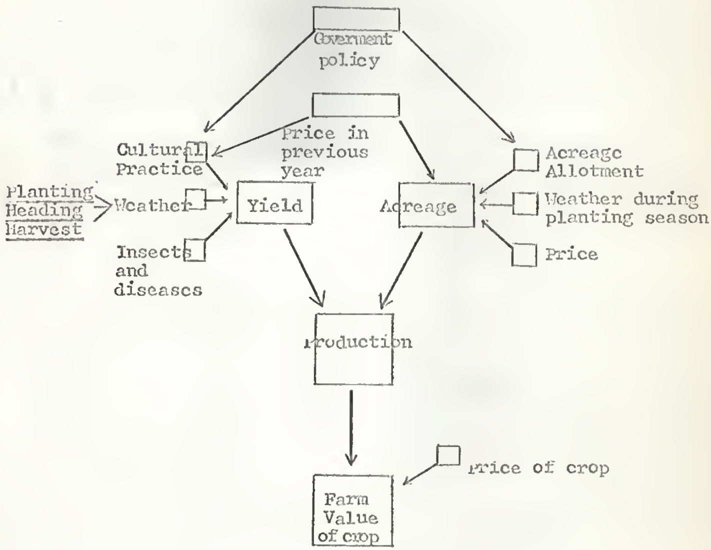

Fig. 7 A revised model for crop production and farm value of crop. (Original source: Shuffett, D. Milton. "The Demand and Price Structure for Selected Vegetable." U. S. Dept of Agriculture, Technological Bulletin 1105, p. 18, 1954.

As shown in Appendix B, if a cycle exists, the estimates of the technological effects using a moving average and least squares tend to overestimate or underestimate the actual trend in the two ends of periods, especially when cycles is irregular. Thus, the technique of trend moved might introduce errors into the first approximation of weather effect, Y_W, which is a measure of the deviation around the trend.[1] It is assumed that the measurement error in Y_W, the dependent variable of equation (4-4), is not systematic,[2] and that there is no measurement error in the independent variables of equation (4-4). The occurrence of random error in the dependent variable will lower the correlation coefficient, and increase the standard error, but it will not have significant effect upon the regression coefficient,[3] with which we are mainly concerned in this study.

To compensate for the different effect of weather during the growing season, weather variables of three months are included in the equation, which stand for the planting, heading and harvest season. So the regression model of equation (4-4)

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[1] There is no difference between taking out BT from equation (4-1) and taking out Y' from Y in the regression analysis (see Appendix C) except the constant term.

[2] When the technological improvements are not perfectly a linear trend even though we assume it is a linear trend, then the introduced error in the dependent variable of equation (4-4) will not be systematic .

[3] Ezekiel and Fox, op. cit., pp. 312-313.

is:

(4-5) $Y_w = f$ (Weather at planting, heading, harvest)

The mathematical form is:

$$(4\text{-}6) \qquad Y_w = a + bW_i + cW_i^2 + e.$$

where, Y_w is the variation in yield (bu. per acre) with trend removed;

W_i are representing of planting, heading and harvest;

W_i^2 are the squares term of W_i. The square term allows extreme weather conditions to show a nonlinear effect on yield.

e is the error term.

Weather Impact on Farm Income from Cash Crops

In the study of the impact of weather on farm income from cash crops, trend is estimated by including a time variable in the equation--unlike in the previous case where trend is removed from yield. There is a considerable trend in the price variable as well as in the technological improvement, hence, if the technological effects were removed by using the method of trend removal before the regression analysis, some of the statistical information such as price effect would be discarded. To avoid this defect, both the time variable and price variable are involved instead of using trend removal. However, such approach might give rise to supurious regression coefficient and coefficient of determination in case the price variable

is highly correlated with time variable. Weather indirectly influences farm income from cash crops through crop production, but it is treated as a direct variable in the equation. It may also show a relationship between weather and price: favorable weather leads to large production and thus results in low price, and vice versa. No attempts are made to study this. The above statements are expressed as follows:

(4-7) Farm Income = f(Weather, Time variable, Price index)

The weather variables in equation (4-7) are in quadratic form.

Weather Impact on Number and Farm Value of Cattle

The functional relationships among weather, feed production, farm value of cattle and prices are more complex. To use a single equation involving these variables might cause a less reliable estimate of regression coefficient because these different, but correlated, endogeneous variables have a similar affect in the same sample period.[1] Therefore, a recursive model is used. The procedures are summarized below:
(1) Estimate the influence of weather on feed production; (2) Estimate the influence of the estimated feed production on number of cattle; and (3) Estimate the influence of estimated

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[1]Valavanis, Stefan, Econometrics, McGraw-Hill Book Co., Inc., 1959, pp. 120-121.

number of cattle and estimated T.D.N. on farm value of cattle.

The relationships among these endogeneous and exogenous variables are treated as a recursive relationship: feed yield is largely influenced by the exogenous variables of weather and technology; number of cattle is mostly determined by feed production and prices; and farm value of cattle is related to the number of cattle, feed yield and price. This situation is illustrated by the following equations:

Endogenous Variables	Exogenous Variables
Feed Yield (Ton per acre in TDN)	$+b_1(DSI)_{June}$ $+b_2(DSI)_{Aug.}$ $+b_3(DSI)^2_{June}$ $+b_4(DSI)^2_{Aug.}$ $+b_5(Time)$ $+e_1 = 0$
Number of Cattle $+b_6\begin{pmatrix}\text{Estimated}\\\text{Feed Yield}\\\text{x(acre)}\end{pmatrix}$	$+b_7(\text{P.I. of Cattle})$ $+b_8(\text{P.I. of TDN})+b_9(Time)$ $+b_{10}(\text{Price ratio})$ $+e = 0$
Farm Value $+b_{11}\begin{pmatrix}\text{Estimated}\\\text{No. of}\\\text{Cattle}\end{pmatrix}$ $+b_{12}\begin{pmatrix}\text{Estimated}\\\text{Feed}\\\text{Yield}\end{pmatrix}$	$+b_{13}(\text{P.I. of Cattle})$ $+e_3 = 0$

Cattle numbers as endogenous variables is a function of the predetermined endogenous variable, feed production, and it is also one of the factors in determining the endogenous variable of farm value of cattle. In the same way, the other factors can be explained. Since there exists an ordering of the endogenous variables such that the coefficients of the matrix of the endogenous variables are triangular, the model is said to be recursive. In the above model, it is assumed the error terms are neither mutually correlated nor serially

correlated. To avoid the eorrelation between endogenous variable and the unexplained residual, the estimated value rather than actual value is used in the equation.[1]

From Fig. 8, the model ean bc written as below:

(4-8) Average T.D.N. (ton per acre) = f(Drought severity index of June, $June^2$, Aug., $Aug.^2$, time variable)

(4-9) Number of Cattle[2] = f(Estimated average $T.D.N._{t-2}$) x Acres, (Estimated average $T.D.N._{t-1}$) x Acres, Price index of $T.D.N._{t-2}$, of $Cattle_{t-1}$, Priee ratio of eattle priee index to T.D.N. priec $index_{t-1}$, Time variable)

(4-10) Farm Value of cattle = f(Estimated number of cattle, Estimated $T.D.N._{t-1}$, Price index of cattle)

In equation (4-8), June and August, being the planting and heading season, are regarded as time that weather phenomena have greater influence on feed produetion.

Basis for Selecting the Independent Variables

Variables in the multiple regression equation should be selected on the basis of what is believed to be a logieal causes-and-effect relationship, and thus are expected to make a significant eontribution given the selection of a proper mathematical equations. However, this does not imply that only those independent variables whieh are correlated with

[1] Foote, Op. eit., pp. 64-65.

[2] This approaeh ignores that weather have effect on the number of aeres planted for only acres harvested are eonsidered in this equation.

dependent factor should be chosen, because these relationships may be due to chance fluctuation rather a true relationship. This could result in faulty forecasting.[1] The following criteria are used to choose the independent variables.

Crop Calendar

"Plants pay but little attention to a calendar; they germinate, bloom, ripen their seeds according to the season, not according to the calendar."[2] Of course, an ideal selection of growth season in each year should be based on this concept. Since detail information about the growth season in each year is not available, an average crop calendar of 1952-1961 is used. (Table 9)

The growing season of crops may be roughly divided into three periods: planting, growing and heading, and maturing. Only three months are selected to represent the growing season.

Correlation of Independent Variables

One of the crucial assumptions of multiple regression analysis is the absence of multicolinearity.[3] However, such

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[1]Ezekiel and Fox, op. cit., p. 436.

[2]Sanderson, op. cit., p. 196. Original source: Alsberg, C. L., and Griffing, E. P., "Forecasting Wheat Yields from the Weather," Stanford University, Food Research Institute, Wheat Studies, 5:1-44, Nov. 1928, p. 22.

[3]Malinvaud, E., op. cit., pp. 187-192.

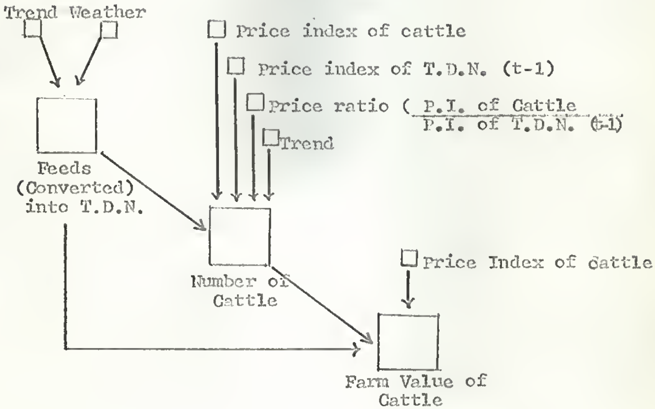

Fig. 8 A recursive model for number and farm value of cattle on farm.

TABLE. 9. -- Percentage of acreage sown, headed, turned color, ripe, mature, tasseled, dented of crops by specified month, Northwestern Kansas,[a] 1952-1961 Average.

Items	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Total%
Wheat									
						(previous year)			
Sown						84	14		98
Headed		68	32						100
Turned			92						92
Ripe			58						58
Harvested			22	77					99
Corn									
Planted	3	66	31						100
Tasseled				36					36
Dented					26	68			94
Mature						70	29		99
Harvested							60	35	95
Sorghum									
Planted		12	82						94
Headed					75	17			92
Mature						46	49		95
Harvested						59	35		94

[a]Source: Kansas Crop and Livestock Reporting Service, Planting, Development, and Harvest of Major Kansas Crops, Federal Building, Topeka, Kansas, Feb. 1963.

an assumption in an empirical study is usually not very plausible. Actually, the independent variables are more or less intercorrelated which might result less reliable the regression coefficients. Drought severity indices in successive months are highly correlated. (Table 10). To lessen the effect of multicollinearity, every second month during the growing

season is selected for corn and grain sorghum. The interval of the months selected as independent variables for wheat is equal or more than two months.

TABLE 10. -- Matrix of correlation coefficients among drought severity index, Northwestern Kansas, 1931-1965.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1 (Jan.)	1.00	0.96	0.89	0.85	0.78	0.71	0.72	0.73	0.67	0.58	0.50	0.51
X_2 (Feb.)		1.00	0.93	0.90	0.83	0.75	0.74	0.74	0.65	0.58	0.51	0.52
X_3 (Mar.)			1.00	0.97	0.93	0.85	0.84	0.84	0.74	0.68	0.62	0.62
X_4 (Apr.)				1.00	0.95	0.89	0.88	0.89	0.79	0.72	0.66	0.67
X_5 (May)					1.00	0.95	0.93	0.91	0.84	0.81	0.75	0.75
X_6 (June)						1.00	0.98	0.95	0.92	0.89	0.82	0.82
X_7 (July)							1.00	0.98	0.95	0.92	0.86	0.85
X_8 (Aug.)								1.00	0.94	0.90	0.84	0.84
X_9 (Sept.)									1.00	0.96	0.91	0.90
X_{10} (Oct.)										1.00	0.96	0.95
X_{11} (Nov.)											1.00	0.99
X_{12} (Dec.)												1.00

Number of Variables

Selecting the number of variables for an equation presents a problem as explained by Williams.[1]

[1]Williams, E. J., Regression Analysis, New York, John Wiley & Sons, Inc., 1959, p. 23.

> "It is undesirable to include too many variables in the regression equation, first, because three or four variables if suitably chosen will generally provide a satisfavtory relationship, ..., and third, because an equation with many variables in it can seldom be easily applied in subsequent prediction."

The greater the number of variables in the equation, the higher the multiple correlation coefficient, but this might cause less accurate specification of the partial regression coefficient. So in the study of the impact of weather on farm income from cash crops, in addition to a price index and a time variable, drought severity indices for only two months are used to explain the weather influence: October$_{t-1}$ and August, where October$_{t-1}$ stands for the weather influence of the previous period on wheat and August stands for the weather influence on corn and grain sorghum income.

<u>Other Factors</u>

Technological improvements and price level are two other important contributing factors to farm income from cash crops.

The above statements are summarized as follows:

(1) October$_{t-1}$, April and June are choses as the months representing the growth season for wheat.

(2) June, August and October are chosen as the months representing the growth season for grain sorghum and corn.

(3) In the study of the impact of weather on farm income from cash crops, only October$_{t-1}$ and August are selected. Price index and time variable are also considered.

To choose independent variables in the recursive model for

the study of the impact of weather on numbers and farm value of cattle, several other factors are also taken into consideration:

(1) Reading Fig. 4, if we shift the base in T.D.N. production two years to the left of the origin, then its cyclical movement is more consistent with that of cattle number than other matchings. This suggests that in addition to lagged output of T.D.N.$_{t-1}$, production of T.D.N.$_{t-2}$ also contributes to the production of cattle. Feed production is thought of influencing cattle production in two ways: First, feed production reported in t period, which is actually harvested in October$_{t-1}$, will be one of the factors in affecting cattle production both in t and t-1 period. Second, the amount of feed production in period t-1 but reported in t period might also affect decision making about cattle numbers in t+1 period. Therefore, output of two preceeding periods T.D.N.$_{t-2}$ are considered in estimating cattle numbers as shown in equation (4-9).

(2) Price index of cattle and of T.D.N. indicates the response of cattle numbers to price change in absolute value. Since these two price indices are correlated at some extent, therefore, to show the effect of the relative change in price indices on production, the price ratio of cattle price index to T.D.N. price index is also considered in equation (4-9).

V ANALYSIS AND ECONOMIC INTERPRETATION

Interpretation of the estimated equations is divided into three parts: (1) to explain the estimated statistical results in which some statistics such as regression coefficients, T test, coefficient of determination, standard error, etc., are discussed; (2) to estimate the impact of weather on crop yield and farm income from cash crops and on cattle production and farm value of cattle; (3) to discuss the implication of the equations from an economic point of view.

The Impact of Weather on Crop Yield

Statistical Results

Regression Coefficient and T Test

Table 11 shows the regression coefficients and T values for weather variables. In this study, the drought severity index is a better measurement of weather than is monthly moisture departure based on T values and the coefficients of determination, R^2.

Most of the regression coefficients of the squares term in equation (5-1), (5-2) and (5-3) are significant, at 1%, 5% or 10% level, indicating that the relationship between crop yield and weather is non linear, but no higher degree is considered. All the signs of the regression coefficients of these equations are consistent with each other in the same month with the exception of June in equation (5-1) and October

TABLE 11. -- Characteristic of estimated function of yield variation[a] due to weather in wheat, corn and grain sorghum, Northwestern Kansas, 1932-1965.

Eq. No.	Dependent Variables	Basic Yield	Regression Coefficient of									
			Oct_{t-1}^2	Apr^2	$June^2$	Aug^2	Oct^2	Oct_{t-1}	Apr	June	Aug	Oct
(5-1)	Wheat	-0.43	0.01	0.20**	-0.14			0.23	0.69**	0.58		
	("t"value)		(0.09)	(1.50)	(-1.23)**			(0.75)	(0.10)	(1.29)**		
(5-2)	Corn	-1.54			-0.11	0.24**	0.13			1.96*	2.26*	0.02
	("t"value)				(-0.90)	(2.01)	(-1.17)			(-2.94)	(4.86)	(-0.04)
(5-3)	Grain Sorghum	1.33			-0.31**	0.33*	-0.25			-2.13*	2.26*	0.67***
	("t"value)				(-2.27)	(2.52)	(2.08)**			(-2.84)	(3.32)	(1.19)
	(In the above, the independent variables are drought severity index as measures of weather.)											
(5-4)	Wheat	0.63	-0.54*	0.09	-0.06			3.64*	0.32	0.82		
	("t"value)		(-2.56)	(0.51)	(-0.63)			(4.31)	(0.60)	(2.85)		
(5-5)	Corn	0.27			-0.07*	-0.09	-0.16			0.39**	2.69*	0.31
	("t"value)				(-0.58)	(-0.31)	(-0.60)			(1.01)	(4.59)	(0.28)
(5-6)	Grain Sorghum	0.63			-0.15*	-0.21	0.07			0.57**	2.59*	-0.46
	("t"value)				(-1.08)	(-0.67)	(0.23)			(1.29)	(3.93)	(-0.36)

[a] Yield variation (Dry Land) is bushel per acre and trend has removed.

* Means significance at 1% level in one Tail T test.

** Means significance 5% level in one Tail T test.

*** Means significancc at and near significance at 10% level in one tail T test.

in equation (5-3). Weather effect in the same growing season is similar for various crops studied.

Based on the sign and value of the regression coefficients of drought severity index in each month, favorable weather conditions for crop growth are summarized as follows:

(1) Wheat: 'wetter' than normal weather at planting and in April, and normal weather at harvest.

(2) Corn and grain sorghum: somewhat 'dryer' than normal weather at planting and 'wetter' than normal weather at heading.

These conclusions are subject to the effect of multicollinearity. Since the independent variables are highly correlated, the regression coefficients become less reliable.[2] This makes it difficult to identify the separate influence of the independent variables, and the regression coefficient are less reliable. However, if forecasting is a primary objective, then, multicollinearity may not be too serious, provided the intercorrelations of the independent variables may reasonably be expected to continue in the future. Multicollinearity may be the reason that an unreasonable conclusion of somewhat 'dryer' than normal weather at planting season being favorable for corn and sorghum is obtained.

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[1] For the implication of 'wet', 'dry' and 'normal weather' in corresponding to drought severity index see Table 1.

[2] Statistically, this can be expressed as:

$$S^2_{b\,12.34\,\cdots\,m} = \frac{S^2_{1.234\,\cdots\,m}}{n\,S^2_2\,(1 - R^2_{2.34\,\cdots\,m})}$$

If the drought severity indices of the months June, August, and October are varied, yield variation in yield is obtained and listed in Table 12 and on Fig. 9. It indicates that a drought severity index of 2 in June, August and October will give the maximum yield, i.e., it is the best favorable weather for grain sorghum growth.

To compare the response of weather for plant growth between corn and grain sorghum, another statistic is used. Table 13 shows 'testing the difference between two regression coefficients from two equations.' Corn and grain sorghum are selected for study for they grow at much the same season. As shown in Table 13, the regression coefficients of June^2, August, and October are significantly different at 1% and 5%. The following conclusions are drawn from this result:

(1) In the growth season, extreme weather deviation from normal weather are expected to be more detrimental to corn than to grain sorghum as shown by the effect of June^2 variable.

(2) In the heading season, 'wetter' than normal weather is expected to be more favorable to corn than for grain sorghum as shown by the effect of August variable.

(3) At the harvest season, 'wetter' than normal weather is expected to be more favorable to grain sorghum than to corn as shown by the effect of October variable.

(4) The effect of June, August^2 and October^2 variables are expected to be the same for these two crops.

Of course, such a comparison is also subject to error due

TABLE 12. -- Yield variation[a] reflected by drought severity index, grain sorghum.

Drought Severity Index of June, August and October (1)	Yield Variation (bu./acre) (2)
5	-0.42
4	0.85
3	1.66
2	2.01
1	1.90
0	1.33
-1	0.30
-2	-1.19
-3	-3.14
-4	-5.55
-5	-8.42

[a]Trend has removed already.

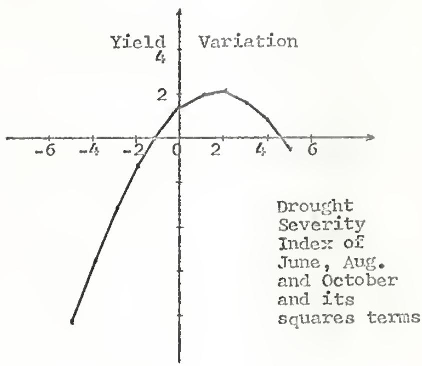

Fig. 9 Yield variation reflected by drought severity index, grain sorghum

TABLE 13. -- Testing the significance of the difference between the regression coefficient b_1 and b_2 of two separate equations. $H_0:(b'_1 = b'_2, \sigma_1^2 = \sigma_2^2 = \sigma^2)$ against $H_a:(b'_1 \neq b'_2)$

Variables (Drought Severity Index)	Grain Sorghum				Corn				
	b_1	S_{b_1}	T_{b_1}	$S_{x_1} = S_{x_2}$	b_2	S_{b_2}	T_{b_2}	$S_{b_1-b_2}$	T
$June$	-2.216	0.743	-2.849	3.019	-1.960	0.666	-2.943	0.511	-0.501
$June^2$	-0.311	0.137	-2.267	7.977	-1.110	0.122	-0.902	0.188	4.245*
August	2.260	0.681	-3.322	3.666	2.956	0.607	4.867	0.422	-1.649**
$August^2$	0.330	0.131	2.517	10.577	0.236	0.117	2.018	0.140	0.670
October	0.674	0.566	1.190	3.590	-0.022	0.503	-0.044	0.431	1.614**
$October^2$	-0.251	0.120	-2.084	10.337	-0.126	0.107	-1.170	0.140	-0.891

P.S.

1. $S_{y_1 \cdot x} = 6.241$. $S_{y_2 \cdot x} = 6.336$. $F = 1.015$

2. $D.F. = n_1 + n_2 - 4 = 64$.

3. Summary of formula:

$$S'^2_{y_1 \cdot x} = \frac{(n_1-2)S_{y_1 \cdot x} + (n_2-2)S^2_{y_2 \cdot x}}{n_1 + n_2 - 4} \quad . \quad S'^2_{b_i} = \frac{S'^2_{y \cdot x}}{(n_i-1)S_i^2}$$

$$S^2_{b_1-b_2} = S'^2_{b_1-b_2} = \quad . \quad T = \frac{b_1 - b_2 - 0}{S_{b_1} - b_2} .$$

* means significance at 1% level in one tail T test.

** means significance and near significance at 5% level in one tail T test.

to multicollinearity among variables.

Coefficient of Determination

Table 14 shows the coefficient of determination and the partial correlation coefficient of adding each independent variable in the sequence as they appear in the equation. It is useful to test the quadratic form first,[1] so all the squares term are listed first. Coefficients of determination in equations (5-1)', (5-2)' and (5-3)' are significant at 1% level. Based on the coefficient of determination, drought severity index gives a more satisfactory fit than the variable of monthly moisture departure. Owing to multicollinearity the increment of the correlation coefficient by adding the last variable is nearly zero as shown in Table 14.

Estimating the Influence of Weather on Crop Yield

The following procedures are used to estimate the impact of weather on crop yield: (1) By substituting a drought severity index of zero into equations (5-1), (5-2) and (5-3), thus giving the expected crop yield at normal weather; (2) The difference between the reported and the expected yield is the estimated influence of weather on crop yield (Table 15).

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[1]Fryer, H. C., Concepts and Methods of Experimental Statistics, Allyn and Bacon, Inc., Boston, 1966, p. 461.

TABLE 14. -- The r[illegible]ive importance of independent variables in the multiple regr[illegible]n analysis of wheat, corn and grain sorghum.

Eq. No.	Dependent Variables		Independent Variables									
			[illegible]$_{t-1}^2$	Apr	June^2	Aug^2	Oct^2	Oct$_{t-1}$	Apr	June	Aug	Oct
(5-1)	Wheat	D.F.	[illegible]	31	30			29	28	27		
		R.	[illegible]7	0.10	0.18			0.63	0.77	0.78		
		Increment			0.08			0.45	0.14	0.01		
(5-2)	Corn	D.F.			32	31	30			29	28	27
		R			0.05	0.16	0.27			0.74	0.89	0.89
		Increment				0.11	0.11			0.47	0.15	0.00
(5-3)	Grain Sorghum	D.F.			32	31	30			29	28	27
		R			0.29	0.33	0.40			0.74	0.89	0.89
		Increment				0.04	0.07			0.47	0.15	0.00

(In the above the [illegible]pendent variables are drought severity inde[illegible]easures of weather)

Eq. No.	Dependent Variables											
(5-4)	Wheat	D.F.	[illegible]	31	30			29	28	27		
		R	[illegible]	0.29	0.30			0.70	0.71	0.79		
		Increment		[illegible].04	0.01			0.40	0.01	0.08		
(5-5)	Corn	D.F.			32	31	30			29	28	27
		R			0.30	0.32	0.34			0.52	0.78	0.78
		Increment				0.02	0.02			0.18	0.25	0.00
(5-6)	Grain Sorghum	D.F.			32	31	30			29	28	27
		R			0.15	0.19	0.20			0.42	0.71	0.71
		Increment				0.04	0.01			0.25	0.26	0.00

(In the above, th[illegible]ndent variables are monthly moisture den[illegible]as measures of weather)

TABLE 15. -- Estimated influence of weather on crop yield (dry land) reported as deviation from that expected if weather were normal, Northwestern Kansas, 1932-1965.

	Wheat		Corn		Sorghum	
Year	Reported (bu/acre)	Estimated Influence of Weather (bu/acre)	Reported (bu/acre)	Estimated Influence of Weather (bu/acre)	Reported (bu/acre)	Estimated Influence of Weather (bu/acre)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1965	17.73	-0.91	20.00	-3.57	22.99	-1.61
1964	20.00	-0.70	17.73	2.17	18.91	0.21
1963	21.06	-0.92	26.21	1.96	33.89	4.19
1962	26.32	1.90	29.37	01.01	36.00	8.86
1961	23.06	1.09	21.86	6.13	28.51	7.07
1960	38.03	3.89	22.27	5.11	22.91	5.41
1959	21.69	-1.59	23.66	0.91	22.24	1.76
1958	29.72	4.38	32.13	14.37	29.29	13.69
1957	23.18	-0.34	20.94	6.43	16.96	6.43
1956	10.19	-7.84	15.05	3.36	6.38	-12.33
1955	19.68	-4.63	7.41	1.79	5.81	- 6.06
1954	14.56	-2.67	15.58	0.85	14.51	-1.21
1953	16.04	-2.87	15.25	5.71	14.35	0.48
1952	22.24	4.05	17.95	11.84	15.85	1.55
1951	14.25	0.09	25.23	13.60	17.48	5.85
1950	19.34	3.58	24.90	7.72	22.31	12.54
1949	10.74	2.53	25.42	13.57	24.60	10.14
1948	19.25	3.17	16.12	6.40	15.33	8.10
1947	22.59	6.13	14.18	11.75	12.82	8.99
1946	21.26	-0.72	10.63	14.23	12.09	3.60
1945	22.26	5.14	18.46	3.72	12.51	10.91
1944	16.35	5.08	29.69	7.23	24.95	12.38
1943	17.55	0.59	12.07	7.89	10.43	5.82
1942	23.07	9.76	19.92	5.15	10.24	5.19
1941	15.60	0.53	18.70	7.14	15.08	3.05
1940	8.09	-6.45	5.50	7.90	7.70	-7.28
1939	6.43	-4.61	4.94	6.35	4.67	-7.14
1938	11.66	-3.27	5.50	8.57	7.36	-3.43
1937	5.63	-5.89	3.06	6.35	4.59	-7.50
1936	7.29	-6.03	3.73	8.57	1.00	-9.11
1935	7.47	-3.31	4.11	2.92	1.93	-6.25
1934	5.63	-5.52	1.69	8.35	1.00	-9.06
1933	6.88	-4.04	12.74	0.93	1.93	-1.05
1932	10.75	-0.48	11.89	7.90	9.54	1.60

Mean: -0.32 bu/acre Mean: -2.65 bu/acre Mean: 1.72 bu/acre

Standard deviation: 4.18 Standard deviation: 7:89 Standard deviation: 7.33

Comparing signs, the estimated weather effect on these three crops yield in Table 15, shows 27 years out of 34 years are the same sign, but their figures are different from crop to crop. For the period 1932-1965, the yearly average estimated weather influence is a net loss of -0.32 bu. per acre for wheat, a net loss of -2.65 bu. per acre for corn, and a net gain of 1.72 bu. per acre for grain sorghum. Thus the adverse affects of weather have been greater in wheat and corn than favorable weather, but for grain sorghums just the opposite.

Weather Fluctuation and Crop Yield Variation

The problem of a climatic cycle has been viewed differently by various authorities. Mitchell believed that "we are ready to close in on the problem of periodicities in climate."[1] However, Plamer suspected that drought cycles tend to occur about every 20 years in the central United States.[2] Bean also indicated there exists a cyclical weather.[3]

These different conclusions may be partly due to the different definition of cycle. Some regarded cycle as being a very rhythmic and regular oscillation, others regarded cycle as being fluctuation. Secondly, the data of a few years is

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[1] Mitchell, J. Murray, Jr., "A Critical Appraisal of Periodicities in Climate," CAED Report 20, Ames, Iowa, 1964, p. 193.

[2] Palmer, "Climatic Variability and Crop Production," *op. cit.*, p. 186.

[3] Bean, Louis, H., "The predictability of Cycles, Trends and Annual Fluctuations in Weather and Crops," CAED Report 20, Ames, Iowa, 1964, p. 165.

insufficient to conclude whether or not cycles exist.

Rather than dealing with the investigation of weather cycle, this study is primarily concerned about the relationships between the weather fluctuation and crop yield variation. Several considerations are taken into account.

Yield variation is related to weather fluctuation, and is not regarded as accidental events. From Fig. 3 and 5, the peak and tough of crop yield are consistent with that of drought severity index.

However, in the Great Plain, even though weather is still one of the main factors affecting yield and production, it is no longer regarded as the solely deciding factors. As technology improves, expecially in irrigation, the relative impact of weather on production becomes less.

Weather effects on the various crops are mostly the same direction indicated by the sign of regression coefficients, but not the same in magnitude. Generally speaking, grain sorghum is more drought resistant than corn. As for the year-to year variation, grain sorghum is more stable than corn. The standard deviation of the estimated weather effect on various crops (Table 15) is 4.18 for wheat, 7.82 for corn and 7.33 for grain sorghum. This also implies that corn is more sensitive to weather fluctuation than other crops.

Weather influence is related to the crop-growing season. Drought sometime impedes emergence of seeds. Some of the abandonment is caused by severe drought during the planting

season.[1] The planting season should be an important period of plant growth. However, since data used in this study is yield per acre harvested instead of yield per acre planted, the role of the planting season is partly ignored. Based on the partial correlation coefficient and regression coefficient, weather during the planting season has less affect on yield than weather during the heading season. The heading season affects the plant structure and productivity and is thus the most important period in affecting crop production indicated by its larger partial coefficient and regression coefficient than other seasons. At the harvest season, crops have completed their growth and are strong enough to withstand bad weather, so its effect is less than that of other seasons.

The Impact of Weather on Farm Income from Cash Crops

Statistical Results

The estimating regression equations are presented in Table 16. Using monthly moisture departure as the independent variables gives a more satisfactory fit than using drought severity index. But the difference of R^2 between these two

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[1]The simple correlation coefficient between the ratio of the abandoned acres sown and October$_{t-1}$ in wheat is 0.59.

equations (Eq. 5-7, 5-8) is very small. All of the variables are significant at 1%, 5% or 10% level except Oct^2_{t-1} in equation (5-7). The coefficient of determination, R^2, is very high, 0.82 for equation (5-7) and 0.87 for equation (5-8).

TABLE 16. -- Characteristic of estimated function of farm income from cash crops.[a] Northwestern Kansas, 1932-1965.

Eq. No.	Dependent Variables	Basic Value	Regression Coefficient						
			Oct^2_{t-1}	Aug^2	Oct_{t-1}	Aug.	Price I.	Time Var.	R^2
(5-7)	Farm Income (million $)	2.48	0.78	-0.28	2.22	1.06	13.02	0.33	0.82
	("t" value)		(0.4)	(-1.3)**	(2.9)*	(1.6)**	(4.1)*	(1.2)***	
(The independent variables are drought severity index as measures of weather)									
(5-8)	Farm Income (million $)	9.33	-1.12	-1.41	11.38	2.61	10.23	0.45	0.87
	("t" value)		(-2.1)**	(-2.2)*	(5.7)*	(2.3)**	(3.6)*	(1.9)**	
(The independent variables are monthly moisture departure as measures of weather)									

[a] Farm income includes cash crops of wheat, corn and grain sorghum.

* means significance at 1 percent level in one tail T test.

** means significance at 5 percent level in one tail T test.

*** means significance and near significance at 10 percent level in one tail T test.

Estimating the Influence of Weather on Farm Income from Cash Crops

The influence of weather on farm income from cash crops estimated by calculating the deviation of reported income from expected income if weather were normal. Normal weather is considered as having drought severity index of zero and the corresponding value of other factors, i.e., price index and trend, into equation (5-7), it gives the expected income at normal weather while holding other factors constant, (col. 2 of Table 17). The difference between reported income and expected income is the estimated influence of weather on farm income from cash crops (col. 3 of Table 17). In twenty-two years of thirty-four years weather has an adverse affect on income as shown by the minus signs. Since the standard error of equation (5-7) is large (10.799 million $), some allowance of error should be made for these estimates, but nevertheless the estimates seem to be reasonable.

The Impact of Weather on Production and Farm Value of Cattle

The recursive model in this study seems to be a reasonable model to study the impact of weather on cattle production and reported farm value of cattle. The correlation coefficient between reported total T.D.N. and estimated total T.D.N. is 0.90, and between reported number of cattle and estimated

TABLE 17. -- Estimated influence of weather on farm income of cash crop reported as deviation from that expected if weather were normal, Northwestern Kansas, 1932-1965.

Year	Reported (million $) (1)	Expected[a] at Normal Weather (million $) (2)	Estimated Influence of weather (million $) (1)-(2) (3)
1965	31.364	41.995	-10.631
1964	31.882	42.583	-10.701
1963	47.880	47.918	-0.038
1962	58.179	48.127	10.053
1961	45.512	45.670	-0.149
1960	74.272	43.737	30.535
1959	47.230	42.495	4.735
1958	68.243	42.588	25.655
1957	37.769	46.975	-9.206
1956	18.127	50.935	-32.808
1955	38.835	51.447	-12.594
1954	41.109	54.380	-13.271
1953	41.180	50.853	-9.673
1952	76.928	52.110	24.818
1951	35.551	52.730	17.180
1950	55.234	47.284	7.950
1949	28.279	44.119	-15.840
1948	48.947	47.161	1.786
1947	82.751	58.356	24.395
1946	56.291	43.759	12.532
1945	51.193	38.579	12.614
1944	31.571	34.719	-3.148
1943	35.097	34.644	0.453
1942	36.742	26.979	9.763
1941	18.724	23.677	-4.953
1940	4.653	19.467	-14.814
1939	3.637	19.626	-15.989
1938	9.895	16.618	-6.723
1937	7.668	24.687	-17.019
1936	8.333	27.140	-18.807
1935	3.659	23.783	-20.124
1934	3.689	23.783	-20.094
1933	4.911	14.246	-9.335
1932	4.113	7.897	-3.784

[a]The standard error of the regression equation is 10.799 (million $).

number of cattle is 0.89.

Table 18 gives the mean and variance of reported data and of estimated data.

TABLE 18. -- Comparison of mean and variance between reported data and estimated data of T.D.N. and of cattle number.

	Average T.D.N. (ton per acre)		No. of Cattle	
Items	Reported	Estimated	Reported	Estimated
mean	0.782 ton/acre	0.733 ton/acre	257,988 heads	257,989 heads
variance	0.070	0.060	2,628 million	2,082 million

These statistics show a high correlation between reported and estimated data, and are evidence that this recursive model is reasonable. Second, the high correlation coefficients and low standard errors of the regression equations, (Table 19), support the recursive model as being a good fit.

Statistical Results

Regression Coefficients and T Test

In these three equations in Table 19, nearly all the regression coefficients have the expected signs with the exception of the price ratio, which will be explained later, and are statistically significant, except the square term of August, at 1%, 5%, or 10% level.

The signs of the regression coefficients in weather variables

TABLE 19. -- Characteristic of estimated function of Weather-Cattle studies, Northwestern Kansas, 1943-1965.

Eq. No.	Dependent Variable	Basic Yield	Regression Coefficient of June^2	August^2	June	August	Time Va.	R^2
(5-9)	Average T.D.N. (ton/acre)	0.450	-0.009	0.002	-0.066	1.115	0.023	0.89
	("t" value		(-2.03)**	(0.56)	(-2.87)*	(5.76)*	(7.17)*	

(In the above, the independent variables except trend are drought severity index as measures of weather.)

Eq. No.	Dependent Variable	Basic Yield	TDN_{t-2}	TDN_{t-1}	P.I of Cattle	P.I. of TDN_{t-1}	Price Ratio	Time Va.	R^2
(5-10)	No. of Cattle	229,984	0.373	0.267	80,777	-108,713	-74,009	5,043	0.79
	("t" value)		(2.40)*	(1.29)***	(1.79)***	(-1.56)***	(-1.43)**	(3.87)	

Eq. No.	Dependent Variable	Basic Yield	Estimated No. of Cattle	Price Index of Cattle	Extimated TDN_{t-1} (ton/acre)	R^2
(5-11)	Farm Value of Cattle (million$)	-28.166	0.000115	13.791	1.061	0.99
	("t" value)		24.21	27.51	(107)***	

* means significance at 1% level in one tail T test.

** means significance at 5% level in one tail T test.

*** means signifieanee and near significance at 10% level in one tail T test.

are consistent with those for corn and grain sorghum equations, which is reasonable as feed, corn and grain sorghum are grown at much the same season.

Time variables both in equation (5-9) and (5-10) are particularly significant, and it seems to be a useful approach to treat trend as a variable. $T.D.N._{t-2}$ has more effect on cattle production than $T.D.N._{t-1}$ in Northwestern Kansas, as explained on page 51.

Price index of cattle has a positive influence on the number which is as expected if the index reflects a final product or an expectation of selling price. Price index of $T.D.N._{t-1}$ has a negative influence. Farm value of cattle is positively related to the price index. However, the negative sign in price ratio,(in equation (5-10), price index of cattle divided by price index of T.D.N., leads to no logical interpretation. An explaination might be that price ratio is highly correlated with price, with price index of cattle and T.D.N., thus making the sign and the regression coefficient unreliable.

Coefficient of Determination

As shown in Table 20, the coefficients of determination are very high for all equations, all being significant at 1% level. The partial correlation coefficients of weather variables determine 75% of the variation in T.D.N. as shown in equation (5-9)'.

Both $T.D.N._{t-1}$ variables determine 64% of the variation in number of cattle as shown in equation (5-10)'. The variable, estimated number of cattle, determines 82% of the variation in

TABLE 20. -- The relative importance of independent variables in the multiple regression analysis of cattle studies.

Eq. No.	Dependent Variable		Independent Variables: June^2	Aug.^{2}	June	Aug.	Time Variable	R^2
(5-9)'	Average T.D.N. (ton/acre)	D.F.	21	20	19	18	17	0.89*
		R	0.31	0.39	0.58	0.75	0.94	
		Δ		0.08	0.19	0.17	0.19	

(The independent variables except trend are drought severity index as measures of weather.)

Eq. No.	Dependent Variable		TDN_{t-2}	TDN_{t-1}	P.I. of Cattle	P.I. of TDN_{t-1}	Price Ratio	Time Variable	R^2
(5-10)'	No. of Cattle	D.F.	19	18	17	16	15	14	0.79*
		R	0.52	0.64	0.75	0.75	0.76	0.89	
		Δ		0.12	0.11	0.00	0.01	0.13	

Eq. No.	Dependent Variable		Estimated No. of Cattle	P.I. of Cattle	Estimated $TDN_{(t-1)}$	R^2
(5-11)'	Farm Value of cattle (million $)	D.F.	19	18	17	0.99*
		R	0.87	0.97	0.99	
		Δ		0.15	0.02	

* indicates significance at 1% level.

reported farm value of cattle, as reported in equation (5-11)'. These results coincide with the postulates made on p. 41.

Since time variable and weather variable are nearly independent, their regression coefficients are comparatively stable in the presence or absence of other variables as the problem of multicollinearity is minimal in equation (5-9). On the contrary, the variable of the estimated cattle number and of price index in equation (5-11) are highly interdependent. This means that an equation that includes either or both variables will not affect the coefficient of determination very much. That is because price index is indirectly derived from farm value of cattle, so that dependent variable and independent variable are correlated prior, which is also a case of multicollinearity.[1]

Estimating the Influence of Weather on T.D.N., Cattle Production and on Farm Value of Cattle

By the same method mentioned on p. 65,[2] the estimation of the

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[1]Wold, Herman, and Jureen, Lars, op. cit., p. 46.

[2]There is another method to estimate the weather influence. If the regression equation is a linear homogenous function, then, partial regression coefficient will correspond to its marginal product by Euler's Theorem. Therefore, the product of drought severity index and its partial regression coefficient is the estimate of weather influence. For Euler' Theorem see Allen, R. G. D., Mathematical Analysis for Economists, St. Martin's Press, New York, 1964, p. 317.

impact of weather on T.D.N., cattle production and on farm value of cattle can be obtained. Following are the computational procedures: (1) Estimate the influence of weather on T.D.N. : Substituting drought severity index of zero and the corresponding value of trend into equation (5-9), this is the expected average T.D.N. at normal weather (col. 2 in Table 21). The difference between reported and expected is the estimated influence of weather on T.D.N. (ton per acre) (col. 3 in Table 21). The equivalent influence of weather on forage production is converted from col.5 in Table 21, (col. 6 in Table 21). (2) Estimate the influence of weather on number of cattle: By substituting ' estimated total T.D.N. at normal weather (col. 4 in Table 21) and the corresponding value of other variables into equation (5-10), it gives the expected number of cattle at normal weather (col. 2 in Table 22). The difference between reported and expected is the estimated influence of weather on number of cattle (col. 3 in Table 22). (3) Estimate the influence of weather on farm value of cattle: By the same way shown above, the results are listed in col. 6 of Table 22.

Comparing col. 3 and col. 6 in Table 22, the signs of the estimated influence of weather on number of cattle and on farm value of cattle are closely related except for 1963. Considering the impact of weather on crop yield and on T.D.N. based on the period of 1943-1965, the influence of weather on corn (col. 5 in Table 15) is similar in sign with that of weather on T.D.N. for eighteen of twenty-three years. Weather has a negative effect

TABLE 21. -- Estimated influence of weather on feed production reported as deviation from that expected if weather were normal, Northwestern Kansas, 1943-1965.

Year	Reported T.D.N. (ton/acre) (1)	Expected T.D.N. at Normal Weather[a] (ton/acre) (2)	Estimated Influence of Weather on T.D.N. (ton/acre) (1)-(2) (3)	Expected Total T.D.N. Normal Weather (2)x (acres/ton) (4)	Estimated Influence of Weather on Total T.D.N. (ton) (3)x (acre) (5)	Estimated Influence of Weather on Forage (ton)(4) /(0.455) (6)
1965	1.14	0.99	0.15	162,276	25,216	55,421
1964	0.63	0.96	-0.34	120,307	-41,887	-92,059
1963	1.22	0.94	0.28	125,014	37,464	82,059
1962	1.20	0.92	0.28	133,225	40,898	89,886
1961	1.13	0.89	0.23	126,114	32,899	72,306
1960	0.77	0.87	-0.10	131,510	-14,780	-32,484
1959	0.85	0.85	0.002	92,018	170	374
1958	1.20	0.82	0.37	73,347	33,290	73,165
1957	0.82	0.80	0.02	160,957	3,647	8,015
1956	0.34	0.78	-0.44	214,703	-120,260	-264,308
1955	0.35	0.75	-0.40	235,963	-126,753	-278,578
1954	0.63	0.73	-0.10	128,990	-17,095	-37,572
1953	0.65	0.71	-0.04	143,961	-10,750	-23,626
1952	0.64	0.68	-0.04	100,183	-7,020	-15,429
1951	0.84	0.66	0.18	120.816	33,777	74,234
1950	0.85	0.64	0.21	84,217	28,831	62,831
1949	0.91	0.61	0.30	76,000	36,891	81,080
1948	0.65	0.59	0.57	74,651	72,530	159,390
1947	0.52	0.57	-0.05	90,817	-8,159	-17,933
1946	0.57	0.54	0.03	90,990	5,209	11,449
1945	0.64	0.52	0.12	105,595	20,818	45,754
1944	0.91	0.50	0.41	87,025	88,640	194,813
1943	0.51	0.47	0.04	88,011	6,543	14,390

[a] The standard error of the regression equation is 0.098 (ton/acre).

TABLE 22. -- Estimated influence of weather on number and farm value of cattle reported as deviation from that expected if weather were normal, Northwestern Kansas, 1945-1965.

	Number of Cattle			Farm Value of Cattle		
Year	Reported	Expected at Normal Weather[a]	Estimated Influence of weather[a] (1) - (2)	Reported (million$)	Expected at Normal Weather (million $)[b]	Estimated Influence of Weather (million$) (4)-(5)
	(1)	(2)	(3)	(4)	(5)	(6)
1965	299,600	324,139	-24,529	29.960	34.087	-4.127
1964	376,700	366,187	10,513	44.074	43.057	1.017
1963	356,000	358,864	-2,864	48.772	47.015	1.757
1962	324,000	311,498	12,502	42.120	39.871	2.249
1961	281,000	258,538	12,462	34.563	33.232	1.331
1960	270,000	256,735	13,247	32.940	31.637	-2.775
1959	273,000	301,480	-28,480	38.766	41.541	-12.721
1958	233,000	340,818	-107,818	26.795	39.516	-9.139
1957	190,000	284,499	-94,499	14.250	23.389	-7.891
1956	235,000	303,355	-68,355	17.191	25.082	2.470
1955	282,700	246,127	36,537	22.616	20.146	-4.170
1954	270,200	295,691	-25,491	20.535	24.706	-1.346
1953	272,510	278,093	-5,583	26.979	28.342	8.503
1952	257,650	188,950	68,700	45.405	34.009	6.046
1951	213,480	149,921	63,559	25.359	26.629	-3.881
1950	210,500	245,022	-34,522	32.357	26.405	-3.881
1949	202,000	219,313	-17,313	26.425	25.359	-2.129
1948	195,700	174,976	20,724	26.763	17.357	2.799
1947	205,500	132,412	73,088	20.157	6.425	9.604
1946	230,500	171,333	59,167	16.029	6.763	7.297
1945	238,700	243,208	-4,508	12.412	12.811	-0.399

[a] The standard error of the regression equation is 27,920.

[b] The standard error of the regression equation is 1.022 (million $).

on farm income from cash crop two years more than on farm value of cattle. The impact of weather on corn and on T.D.N. are the same in sign except for one year. These results are reasonable and imply that weather has less influence on value of cattle than income from cash crops. All the above comparisons are considered by the direction or sign and not magnitude.

The standard error is 0.098 (ton/acre) in equation (5-9), 27,920 number of cattle in equation (5-10), and 1.023 (million $) in equation (5-10). These low standard errors demonstrate the efficient estimate as shown above. Of course, some allowances must be made for discrepancies due to regression error and data deficiency.

Relations of Weather Fluctuation and Cattle Variation

It has been recognized that there is a cyclical variation in livestock numbers. An interesting question is whether livestock cycles are self-generated or result from outside stimuli. Many researchers ascribed livestock cycles to the consequence of outside factors. Hopkins acknowledged that price is an influential factor.[1] Lorie considered that weather can alter temporarily the cyclical pattern in cattle numbers but that cycles are

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[1]Hopkins, John A., Jr., "A Statistical Study of the Prices and Production of Beef Cattle," Iowa Experiment Station, Research Bulletin, No. 101, Dec., 1926.

not caused primarily by weather cycles.[1]

The results of this study revealed that there are some relationships between weather fluctuation and feed yield, and weather fluctuation combined with other factors results in cyclical fluctuation in cattle production and farm value of cattle. This does not mean that weather variables determine all of the year-to-year variation in feed and cattle production, and in farm value of cattle. There are three points worth explanation.

(1) The correlation coefficient between average T.D.N. (ton/acre) and the weather variable is 0.75. This indicates some relations between weather and feed yield. However, it does not follow that weather variables are the only factors affecting feed supply. Decision making regarding feed production and feed supply may also be traced to lagged output of cattle production, acres harvested and prices. The supply function is beyond the scope of this study.

(2) Even though the correlation coefficient between number of cattle and estimated T.D.N._{t-1} and T.D.N._{t-2} is 0.64, feed production is not the only factor affecting cattle production. Other factors such as market demand, price level of feed and cattle, technology, etc. are also the influential factors in determining cattle production. Lagged output of cattle may also

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[1]Breimyer, Harold F., and Thodey, Alan R., "Livestock Cycles and Their Relation to Weather and Range Conditions," CAED Report, 20, Ames, Iowa, 1964, p. 244. Original source: Lorie, James H., "Causes of Annual Fluctuations in the Production of Livestock and Livestock Products," Supplement to the Journal of Business, University of Chicago Studies in Business Administration, Vol. XVIII, No. 1, 1947, p. 60.

be a main factor in determining feed production.[1]

(3) The high coefficient of determination, $R^2 = 0.99$, is sufficient to believe there exists a functional relationship between farm value of cattle and price index feed yield and number of cattle production.

To sum up, weather variables are relevant to feed yield, number of cattle and farm value of cattle. But there is little justification to conclude that the cycle and / or fluctuation of cattle production and farm value of cattle are solely determined by weather.

Alternative Equations that Have Been Tested Without Successful Improvements

Several other attempts were also made to improve these results without notable success. The T value and R^2 were comparatively lower than those reported above. Table 23 shows all the equations which were tested but did not lead to a good fit based on T value and R^2.

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[1] Breimyer and Thodey indicated that "Livestock cycles have more effect on range feed condition than vice versa."....."It is equally or more logical to say that livestock numbers go through cyclical fluctuations and these give rise to a cyclical pattern in the condition of range feed." Breimyer and Thody, *op. cit.*, p. 247.

TABLE 23. -- Other equations that have been tested without any appreciable improvements.

Eq. No.	Dependent Variables	Independent Variables	No. of Va. not signif. at 10% level	R^2	Note[a]
1.	Wheat Yield	Drought Severity Index (D.S.I.) of Oct_{t-1}, Ap., Ap.^{2}, June, June^2.	(4)	0.48	Using moving average to remove trend
2.	Wheat Yield Variation	D.S.I. of Oct_{t-1}, Oct^2_{t-1}, Apr^2, June, June^2.	(4)	0.56	Using least Square to remove trend
3.	Farm Income from Cash Crops	D.S.I. of Oct_{t-1}, Oct^2_{t-1}, Apr., Apr^2, June, June^2, Price Index, Acres.	(1)	0.84	
4.	Farm Income from Cash Crops per Acres Harvested	D.S.I. of Oct_{t-1}, Oct^2_{t-1}, Apr., Apr^2, Price index$_{t-1}$, Time Variable (T), T^2.	(4)	0.86	
5.	Farm Income from Cash Crops	D.S.I. of Oct_{t-1}, Oct^2_{t-1}, Apr, Apr^2, Price index$_{t-1}$, T, T^2.	(5)	0.82	
6.	Average T.D.N. (ton/acre)	D.S.I. of June^2, June, Aug, Aug^2, T, T^2.	(3)	0.89	
7.	Total T.D.N.	D.S.I. of June, June^2, Aug, Aug^2, T, Acre.	(1)	0.84	(Standard error is too high)
8.	No. of Cattle	D.S.I. of June, June^2, Aug, Aug.^{2}, Price Index of Cattle, of feed, T.	(3)	0.75	Not by recursive model
9.	No. of Cattle	D.S.I. of June, June^2, Aug, Aug^2, Price ratio of cattle index to feed price index T.	(1)	0.77	
10.	Farm Value of Cattle	D.S.I. of June, June^2, Aug, Aug^2, Price Index of T.D.N$_{t-1}$, Cattle$_{t-1}$, Cattle$_t$.	(6)	0.79	

[a] Those without notes indicate that they used the same methods as mentioned in the main body.

VI SUMMARY AND CONCLUSION

Drought severity index is a reasonable measurement of weather in Northwestern Kansas; but the application of this index has two limitations: (1) Drought severity indexes in successive months are highly correlated, suggesting thereby that to involve those variables in the same equation may result in the effect of multicollinearity; (2) This index is mainly concerned with moisture condition, and temperature is indirectly reflected in the index. Needless to say, the direct effect of temperature is partly ignored. In addition, the definition of normal weather, as drought severity index equal zero, which is thought of the best favorable weather for crop growth, is very vague. From this study, the maximum value of yield in wheat and corn, with the exception of grain sorghum, did not appear even in the range of drought severity index from -2 to +2. This might be partly due to both inadequate data and defective technique used computint the drought severity index.

Quadratic multiple regression and recursive model are used. These techniques seem reasonably good for weather-crop study. Trend in crop yields is handled by either removing the estimated trend from yield or by including a time variable in the equation.

Crops yield variation in dry land after trend having been removed is closely related to weather fluctuation. But, as technology, especially in irrigation, improves, the fluctuation of crop yield may be reduced. Minor variation in yield, due to weather or other factors, may still occur but the huge loss in

yield such as the one suffered by the farmers in 1934 and 1936, because of bad weather (extreme dry), is expected to be rare.

Variation in yield is intimately associated with fluctuation in weather. Weather may also be one of the factors affecting feed supply, thus affecting cattle production. However it is premature to regard feed production as always an autonomous factor, and cattle production as always a passive factor depending upon feed supply and Nature. This may be oversimplification, but the decision making of feed production may not be independent of cattle production. Other elements, such as lagged output of livestock and price level also influence decision making of feed production. So it is reasonable to infer that feed production is influenced both by weather, livestock production and other elements.

The influence of weather on feed production, number of cattle, and farm value of cattle is also estimated and listed in Table 21 and 22.

APPENCICES

APPENDIX A Statistics

TABLE 24. -- Drought severity index,[a] Northwestern, Kansas, 1932-1965.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1965	-2.20	-1.93	1.74	2.49	2.59	1.05	1.59	1.96	4.18	5.42	4.63	4.38
1964	-1.07	0.27	0.17	0.27	0.41	0.57	1.11	1.81	1.76	2.18	2.23	2.38
1963	3.40	-0.32	0.34	0.55	1.33	1.62	0.17	0.49	2.01	0.42	0.64	0.76
1962	2.24	1.94	2.20	1.40	1.41	2.97	4.20	4.53	4.49	4.40	3.82	3.47
1961	1.19	0.68	0.61	0.58	1.81	2.08	2.13	2.43	2.57	2.08	2.49	2.52
1960	1.93	3.19	3.17	2.80	2.81	3.16	2.82	2.20	1.72	1.94	1.40	1.70
1959	0.40	0.31	0.63	0.27	0.70	1.21	0.16	0.04	0.64	1.73	1.30	1.11
1958	1.82	2.11	2.92	2.82	2.80	2.56	3.54	3.84	0.11	0.37	0.34	0.12
1957	-4.58	-4.49	0.41	0.78	2.14	3.01	3.03	2.99	2.80	2.95	2.65	2.06
1956	-3.26	-3.17	3.49	3.63	4.49	5.18	5.11	5.12	5.63	5.43	4.98	4.83
1955	-2.39	-2.12	2.47	2.84	3.34	3.25	4.12	4.75	3.88	4.01	3.95	3.64
1954	-0.23	-0.75	0.95	1.74	0.91	1.55	2.26	2.40	3.04	2.39	2.71	2.68
1953	-1.70	-1.81	1.85	1.39	1.33	1.78	1.60	1.26	2.04	1.95	0.95	1.50
1952	-3.25	2.92	3.05	3.07	2.84	1.04	0.86	0.91	1.53	1.88	1.66	1.47
1951	-1.09	-1.02	1.27	0.06	0.66	2.09	3.40	3.80	5.11	4.78	4.25	3.74
1950	3.03	3.08	2.56	2.09	1.75	0.86	1.76	3.19	0.17	0.53	0.83	1.09
1949	1.85	1.78	2.44	2.31	2.38	4.41	4.62	5.65	5.03	5.00	4.14	3.53
1948	3.21	2.97	3.18	2.02	2.09	2.61	2.55	2.68	2.08	1.55	1.95	1.77
1947	4.46	4.23	4.35	4.32	4.54	5.57	5.58	5.07	4.11	3.38	3.48	3.60
1946	-0.79	-1.21	0.74	1.84	0.97	0.80	1.08	0.64	0.94	3.97	5.29	4.61
1945	3.96	3.49	2.52	3,14	3.03	3.30	3.35	3.33	3.14	0.31	0.68	0.63
1944	0.91	1.10	1.54	3.72	3.24	3.02	5.25	5.24	4.25	4.18	4.34	3.92
1943	-0.18	-0.41	0.56	0.25	0.55	0.31	0.62	0.91	1.09	1.20	1.50	1.55
1942	4.72	4.52	4.21	5.25	4.41	4.70	4.28	5.23	4.70	4.89	5.29	4.61
1941	0.70	0.57	0.23	1.26	0.97	2.59	3.78	3.84	5.74	5.58	4.98	5.22
1940	-3.74	-3.47	2.88	3,12	3,45	4.19	4.43	4.35	3.76	0.84	0.36	0.39
1939	-3.53	-2.98	2.49	2.48	2.94	2.98	3.79	4.00	4.66	4.89	4.92	4.31
1938	-3.68	-3.80	3.58	3.12	1.86	2.12	2.10	2.88	3.16	3.68	3.64	3.66
1937	-3.80	-3.64	2.48	5.56	4.21	4.67	4.87	4.78	3.93	3.94	3.89	3.79
1936	-1.19	-3.20	3.71	3.12	3.39	4.40	5.30	5.73	4.98	4.76	4.79	4.29
1935	-4.40	-4.34	4.89	3.92	3.97	3.45	4.46	5.02	3.97	3.95	3.27	3.25
1934	-1.53	-0.99	1.46	3.99	3.48	3.75	4.97	5.29	4.94	5.22	4.65	4.41
1933	-1.73	-1.95	2.29	5.17	1.84	2.86	3.28	1.58	1.42	1.87	1.92	1.29
1932	1.47	-0.04	0.20	2.13	0.75	0.28	0.39	1.17	1.02	1.11	1.41	1.44

[a] Source: State climatologist, ESSA-Weather Bureau, Kansas State University, Manhattan, Kansas.

TABLE 25. -- Monthly moisture departure,[a] Northwestern Kansas, 1932-1965.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1965	-0.08	0.06	-0.01	-2.03	-0.80	2.99	1.70	1.17	4.34	2.97	0.37	0.29
1964	-0.53	0.38	-0.38	0.25	-0.93	0.57	1.57	1.81	0.24	1.07	0.44	0.48
1963	0.39	0.46	-0.46	-1.20	-1.90	1.21	0.45	0.75	2.82	0.74	0.42	0.23
1962	-0.03	0.10	0.88	1.26	0.36	4.85	4.04	1.70	0.76	0.67	0.20	0.05
1961	-0.46	0.55	0.00	0.07	2.93	1.31	0.68	1.16	0.70	0.41	1.00	0.37
1960	1.27	2.08	0.58	-0.09	0.67	1.81	0.05	0.72	0.46	0.70	0.55	0.57
1959	0.40	0.07	0.67	-0.59	-1.03	1.67	0.41	0.22	1.08	2.06	0.41	0.07
1958	-0.04	0.68	1.97	0.44	0.61	0.15	3.27	1.48	0.19	0.49	0.02	0.16
1957	-0.34	0.55	0.78	0.90	3.27	3.12	0.86	0.60	0.21	0.78	0.00	0.41
1956	0.01	0.35	1.24	-1.09	2.81	3.28	1.21	1.18	1.87	0.68	0.17	0.46
1955	0.02	0.04	-1.11	-1.36	1.79	0.73	3.16	2.34	0.69	0.95	0.56	0.13
1954	-0.31	0.78	-0.52	-1.95	1.47	2.08	2.27	1.02	1.45	0.60	0.90	0.32
1953	0.52	0.40	-0.43	0.60	0.18	1.67	0.01	0.39	1.64	0.21	1.52	0.83
1952	-0.14	0.01	0.83	0.74	0.20	2.95	0.20	0.31	1.29	0.91	0.04	0.02
1951	-0.15	0.06	-0.67	0.14	1.37	4.26	4.01	1.67	3.05	2.35	0.06	0.09
1950	-0.13	0.52	-0.39	-0.45	0.28	2.02	2.58	3.58	0.31	0.68	0.56	0.44
1949	0.36	0.17	0.61	-1.82	0.64	2.10	0.54	0.88	0.59	0.57	[illegible]	0.24
1948	-0.03	0.13	0.98	0.27	2.96	3.37	2.21	3.33	0.06	0.87	0.56	0.03
1947	0.61	0.33	1.07	0.91	1.51	4.26	1.52	0.15	0.78	0.55	0.71	0.61
1946	-0.30	0.71	0.66	-2.58	2.21	0.20	0.95	1.41	1.68	5.57	2.76	0.17
1945	0.61	0.09	-1.17	1.94	0.48	1.65	1.03	0.72	0.28	0.55	0.65	0.02
1944	1.24	0.40	1.05	5.14	0.22	0.32	6.66	1.17	0.32	0.23	0.94	0.03
1943	-0.24	0.36	-0.36	0.56	0.75	0.51	0.89	0.79	0.49	0.40	0.67	0.26
1942	0.05	0.41	0.31	3.23	0.68	2.12	0.18	2.34	1.60	0.88	0.02	0.50
1941	0.47	0.08	-0.54	2.31	0.36	4.91	3.82	0.99	4.12	0.76	0.04	0.97
1940	0.17	0.17	0.45	-1.17	1.47	3.11	1.75	0.84	0.25	0.83	0.57	0.09
1939	-0.33	0.26	0.35	-0.54	1.62	0.98	2.94	1.34	1.92	1.26	0.86	0.13
1938	-0.38	-0.55	-0.51	0.19	2.13	1.30	0.53	2.21	1.04	1.50	0.55	0.50
1937	-0.06	-0.44	-0.45	-1.45	2.36	0.33	1.52	0.74	0.63	0.66	2.35	0.33
1936	-0.37	-0.49	-1.60	-1.45	0.44	3.88	3.54	2.16	0.28	0.55	0.84	0.01
1935	-0.61	-0.56	-1.90	-1.72	1.52	0.33	3.57	2.27	0.95	0.69	0.44	0.40
1934	-0.51	-0.54	-1.10	-1.80	3.57	1.80	4.22	1.84	0.35	1.40	0.05	0.30
1933	-0.60	-0.57	-1.04	0.03	0.03	3.46	1.87	3.30	0.00	1.07	0.39	0.55
1932	0.37	-0.05	-0.32	0.07	1.39	1.12	0.36	1.81	0.06	0.34	0.66	0.23

[a] Source: State Climatologist, ESSA-Weather Bureau, Kansas State University, Manhattan, Kansas.

TABLE 26. -- Statistics, wheat, Northwestern Kansas, 1930-1965.[a]

Year	Irrigated and Dry Land: Acres Sown (mil.)	Acres Harvest (mil.)	Yield (bu/acre)	Prod. (mil.bu.)	Farm Value (mil. $)	Price (6)/(5)	Irrigated: Acres Sown (1,000)	Yield (bu/acre)	Prod. (bu.) (mil.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1965	1.173	1.057	17.53	18.627	24.029	1.2899	[illegible]	30.0	0.240
1964	1.065	0.926	20.00	18.584	25.724	1.3599	5	-	-
1963	1.058	0.908	21.06	19.152	35.814	1.8699	6	25.5	0.153
1962	0.984	0.921	26.32	24.255	47.287	1.9499	[illegible]	29.0	0.145
1961	1.131	1.024	23.06	21.687	38.169	1.7599	[illegible]	24.3	0.073
1960	1.050	1.049	38.03	38.977	67.434	1.7300	[illegible]	42.6	0.341
1959	1.093	1.185	21.69	22.785	39.711	1.7428	[illegible]	[illegible]	0.136
1958	1.211	0.609	29.72	35.23-	57.822	1.5412	[illegible]	[illegible]	0.129
1957	0.911	0.816	23.18	14.123	26.834	1.9000			
1956	0.110	0.934	10.19	00.826	16.486	1.9800			
1955	1.076	0.986	19.68	18.377	37.673	2.0499			
1954	1.161	1.070	14.56	14.253	31.864	2.2200			
1953	1.324	1.541	16.04	17.159	35.004	2.0399			
1952	1.600	0.817	22.24	34.274	71.001	2.0715			
1951	1.445	1.303	14.25	11.639	24.675	2.1200			
1950	1.335	1.217	19.34	25.195	49.634	1.9699			
1949	1.481	1.206	10.74	13.076	23.798	1.8199			
1948	1.594	1.567	19.25	23.214	45.964	1.9800			
1947	1.487	1.401	22.59	35.402	78.987	2.2311			
1946	1.634	1.381	21.26	29.788	53.618	1.7999			
1945	1.426	1.294	17.55	30.741	45.497	1.4800			
1944	1.493	0.917	16.35	14.995	21.142	1.4100			
1943	1.330	1.328	23.07	22.704	30.364	1.3399			
1942	1.360	1.031	15.60	30.364	31.553	1.0299			
1941	1.140	0.652	8.09	16.084	14.797	0.9199			
1940	1.366	0.663	6.43	5.275	3.217	0.6089			
1939	1.697	1.446	11.66	4.263	2.814	0.6600			
1938	1.698	1.191	5.63	16.854	9.063	0.5377			
1937	1.750	0.959	7.29	6.709	6.977	1.0400			
1936	1.242	0.240	7.47	6.984	6.644	0.9512			
1935	1.078	0.651	5.63	1.796	3.121	0.9023			
1934	1.151	0.344	6.88	3.670	1.546	0.8501			
1933	1.107	0.822	10.75	2.368	2.386	0.6526			
1932	1.092	1.270	14.53	8.840	2.584	0.2922			
1931	1.370	1.379	16.24	18.456	6.001	0.3251			
1930	1.414	1.414	22.39	22.398	12.914	0.5765			

[a] Source: Kansas State Board of Agriculture, [illegible] Facts, Topeka, Kansas, 1930-1965.

TABLE 27. -- Statistics, corn, Northwestern Kansas, 1930-1965.[a]

Year	Irrigated and Dry Land: Acres Sown (1000)	Acres Harvest (1000)	Yield (bu./acre)	Prod. (mil. bu.)	Farm Value (mil. $)	Price (6)/(5)	Irrigated: Acres Sown (1,000)	Yield (bu/acre)	Prod. (bu.) (mil.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1965	Not	31.50	69.65	2.194	2.612	1.1903	-	-	-
1964	Given	21.00	54.69	2.612	1.367	1.1899	11.94	82.81	0.989
1963		46.20	44.22	1.367	2.286	1.1099	14.74	82.66	1.218
1962		51.10	48.00	2.286	1.728	1.0899	16.42	87.36	1.434
1961		40.90	38.77	1.728	2.239	0.9700	13.12	74.59	0.978
1960	84.70	77.90	29.63	2.239	2.286	0.8574	10.40	77.39	0.805
1959	98.50	95.10	28.03	2.286	1.728	1.0200	8.67	71.57	0.620
1958	107.00	104.20	34.66	3.720	2.254	1.1800	7.35	67.20	0.500
1957	99.00	97.00	21.44	2.454	0.667	1.4000	5.57		
1956	48.20	29.54	15.05	0.667	0.471	1.5000			
1955	83.50	42.40	7.41	0.471	3.238	1.6100			
1954	135.70	129.10	15.58	2.011	2.907	1.5198			
1953	132.50	125.40	15.25	1.912	3.297	1.6300			
1952	140.10	134.20	17.95	2.049	5.887	1.6699			
1951	146.10	139.70	25.23	3.525	3.476	1.3500			
1950	107.90	103.40	16.12	2.527	2.748	1.2599			
1949	87.50	85.80	14.18	2.181	1.977	1.3900			
1948	89.70	88.20	10.63	1.422	3.006	2.2199			
1947	100.80	95.50	18.46	1.354	2.074	1.3399			
1946	164.90	145.60	29.69	1.548	4.627	1.2600			
1945	203.00	198.90	12.07	3.673	8.339	1.0000			
1944	293.00	280.90	19.92	8.339	4.139	1.1099			
1943	333.00	308.99	18.70	3.729	4.887	0.7799			
1942	322.00	313.90	5.50	6.253	3.072	0.6199			
1941	276.00	265.00	4.94	4.956	0.715	0.6298			
1940	349.90	135.50	5.31	1.135	0.408	0.6100			
1939	303.50	202.20	3.06	0.669	0.536	0.4996			
1938	285.10	225.50	3.73	1.073	0.482	0.7000			
1937	440.40	416.66*	4.11*	0.689	0.482	1.0884			
1936	749.52	547.71*	1.69*	0.698	0.690	0.8501			
1935	985.26	385.20*	12.74*	1.553	1.912	0.8747			
1934	692.93	905.06*	11.89*	2.249	0.568	0.2787			
1933	1140.26	921.37*	18.90*	0.650	3.214	0.7000			
1932	1120.45	826.76*	25.23*	11.533	1.478	0.1348			
1931	855.41	672.37*	18.90*	10.958	4.076	0.2607			
1930	697.84	672.37*	25.53*	17.167	9.695	0.5647			

[a] Source: Kansas State Board of Agriculture, Farm Facts, Topeka, Kansas, 1930-1965.

The asterisk * indicates that these figures are estimated from col. 2. For computational procedures see p. 30.

TABLE 28. -- Statisties, grain sorghum, Northwestern Kansas, 1930-1965.[a]

Year	Acres Sown	Irrigated and Dry Land: Acres Harvest (mil)	Yield (bu/acre)	Prod. (mil. bu.)	Farm Value (mil. $)	Price (6)/(5)	Irrigated: Acres Sown (mil)	Yield (bu/acre)	Prod. (bu.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1965		0.170	29.87	5.079	4.723	0.9300	23.4	73.0	1.708
1964		0.229	21.80	4.992	5.241	1.0500	-	-	-
1963		0.315	35.69	11.243	9.789	0.8714	14.2	73.8	1.048
1962	Not	0.240	38.34	9.202	8.282	0.9000	13.4	78.0	1.045
1961	Given	0.205	30.48	6.249	5.624	0.8999	10.6	66.6	0.706
1960		0.261	24.82	6.479	4.600	0.9221	10.8	69.1	0.722
1959		0.273	23.96	6.541	5.233	0.7600	11.3	63.9	
1958		0.236	30.79	7.226	6.700	1.3200			
1957		0.610	18.29	11.160	8.482	1.1399			
1956		0.098	7.54	0.739	0.975	1.2299			
1955		0.091	6.80	0.622	0.709	1.1396			
1954		0.319	15.33	4.884	6.007	1.2299			
1953		0.191	15.00	2.868	3.269	0.8599			
1952		0.079	16.33	1.290	2.000	1.0999			
1951		0.209	17.79	3.724	4.990	1.9500			
1950		0.092	22.45	2.062	2.124	1.2499			
1949		0.082	24.60	2.015	1.733	1.1499			
1948		0.060	15.00	0.915	1.007	0.8799			
1947		0.030	12.82	0.388	0.757	1.1599			
1946		0.040	12.09	0.479	0.599	0.5400			
1945		0.075	12.51	0.933	1.073	0.4999			
1944		0.095	24.95	2.374	2.089	0.3999			
1943		0.044	10.43	0.461	0.535	0.5599			
1942		0.056	10.25	0.578	0.312	0.3998			
1941		0.113	15.08	1.079	0.854	0.4999			
1940		0.234	7.70	1.804	0.322	0.3999			
1939		0.159	4.67	0.741	0.415	0.5599			
1938		0.101	7.36	0.741	0.296	0.3998			
1937		0.078	4.59	0.360	0.209	0.5804			
1936		-	-	-	-	1.0400*			
1935		0.087	1.93	0.071	0.127	0.7445			
1934		-	-	-	-	1.0800*			
1933		0.064	7.98	0.514	0.151	0.2939			
1932		0.026	9.54	0.525	0.051	0.2013			
1931		0.025	18.88	0.463	0.112	0.2428			
1930		0.026	17.83	0.471	0.304	0.6447			

[a]Souree: Kansas State Board of Agrieulture, Farm Faets, Topeka, Kansas, 1930-1965.

The asterisk* indicates that these figures are estimated from Kansas data.

TABLE [illegible] -- The computational procedure for estimating yield variat[illegible] due to weather in grain sorghum (dry land), Northwest[illegible]nsas, 1930-1965.

Year (1)	[illegible] (bu/acre) ([illegible] & Dry Land) (2)	Yield[a] (bu/acre) (Irri. & Dry Land) (3)	Difference (2)-(3) (4)	Adjusted Yield of Dry Land (2)-(4) (5)	13-year Moving Average (6)	Trend[b] of the Mov.Avg. (7)	Yield Variation (5)-(7) (8)
1965	[illegible].87	22.99	6.88	22.99		24.55	-2.89
1964	[illegible].80	18.91	2.89	18.91		13.97	-6.39
1963	[illegible].69	33.89	1.80	33.89		23.39	9.17
1962	[illegible].34	36.00	2.34	36.00		22.81	11.86
1961	[illegible].48	28.51	1.97	28.51		22.23	4.95
1960	[illegible].82	22.91	1.91	22.91		21.65	-0.07
1959	[illegible].96	22.24	1.72	22.24	20.98	21.07	-0.16
1958	[illegible].79	-	1.50*	29.29	20.43	20.49	-7.47
1957	[illegible].29	-	1.33*	16.96	20.32	19.91	-4.28
1956	7.54	-	1.16*	6.38	19.43	19.33	-14.28
1955	[illegible].80	-	0.99*	5.81	18.55	18.75	-14.27
1954	[illegible].33	-	0.82*	14.51	17.54	18.17	-4.99
1953	[illegible].00	-	0.65*	14.35	16.76	17.59	-4.57
1952	[illegible].33	-	0.48*	15.85	15.98	17.01	-2.49
1951	7.79	-	0.31*	17.48	14.69	16.43	-0.28
1950	[illegible].45	-	0.14*	22.31	15.31	15.85	5.13
1949	[illegible].60	-	-	24.60	15.62	15.27	8.00
1948	[illegible].33	-	-	15.33	15.96	14.69	-0.69
1947	[illegible]	-	-	12.82	16.00	14.11	-2.62
1946	[illegible]	-	-	12.09	15.49	13.53	-2.77
1945	[illegible]	-	-	12.51	14.63	12.95	-1.77
1944	[illegible]	-	-	24.95	13.85	12.37	11.25
1943	[illegible]	-	-	10.43	12.49	11.79	-2.69
1942	[illegible]	-	-	10.24	10.67	11.21	-2.30
1941	[illegible]	-	-	15.08	9.64	10.63	3.12
1940	[illegible]	-	-	7.70	8.73	10.05	-3.68
1939	[illegible]	-	-	4.67	8.42	9.47	-6.13
1938	[illegible]	-	-	7.36	8.19	8.89	-2.86
1937	[illegible]	-	-	4.59	7.72	8.31	-5.05
1936	[illegible]	-	-	1.00**	8.29	7.73	-8.06
1935	[illegible]	-	-	1.93		7.15	-6.55
1934	[illegible]	-	-	1.00**		6.57	-6.90
1933	[illegible]	-	-	7.98		5.99	0.66
1932	[illegible]	-	-	9.54		5.41	2.80
1931	[illegible]	-	-	18.88		4.83	14.35
1930	[illegible].83	-	-	17.83		4.25	13.58

a [illegible]uted from table 28 by (col. 4-9)/(col. 3-8). Here, the [illegible]es sown in irrigated are assumed to be all harvested.

b [illegible]nd of the moving average 1936-1959 (col. 6) is Y=4.835+0.5801t. b[illegible]ed on 1932 t=1. $r^2 = 0.94$.

* [illegible]rapolated from the trend of 1959-1964. (col.4). D=2.69-0.17t.

** [illegible]bitrary estimation to avoid affecting moving average by i[illegible]egular effects.

TABLE 30. -- Yield variation due to weather in wheat, and corn (dry land); and aggregate price index, Northwestern Kansas, 1930-1965.

Year (1)	Yield Variation due to Weather in Wheat (2)	Yield Variation due to Weather in Corn (3)	Aggregate Price Index (4)
1965	-8.00	-4.44	2.2017
1964	-5.04	-6.26	2.2425
1963	-3.49	2.86	2.6774
1962	2.26	6.57	2.7188
1961	-0.52	-0.39	2.5555
1960	14.94	0.57	2.4325
1959	-0.91	2.51	2.3625
1958	7.61	11.53	2.3950
1957	1.56	0.89	2.7571
1956	-11.13	-4.45	3.0863
1955	-0.96	-11.55	3.1512
1954	-5.60	-2.83	3.4017
1953	-3.63	-2.61	3.1563
1952	3.06	0.64	3.2781
1951	-4.44	8.47	3.3511
1950	1.14	8.69	2.9583
1949	-6.97	9.76	2.7407
1948	2.03	1.00	2.9996
1947	5.85	-0.39	3.8844
1946	5.01	-3.39	2.7891
1945	6.50	4.99	2.4144
1944	1.08	16.77	2.1457
1943	2.77	-0.30	2.1653
1942	8.78	8.10	2.6022
1941	1.80	7.43	1.3740
1940	-5.23	-5.23	1.0762
1939	-6.40	-5.24	1.1137
1938	-0.68	-4.32	0.9081
1937	-6.22	-6.02	1.5530
1936	-4.07	-4.80	1.7667
1935	-2.92	-3.87	1.5343
1934	-4.27	-5.74	1.5596
1933	-2.53	5.86	0.8528
1932	1.83	5.55	0.3907
1931	6.10	13.11	0.5181
1930	8.30	20.29	1.0000

TABLE 31. -- Statistics, silage and forage, Northwestern Kansas, 1943-1965.[a]

	Sorghum for Silage				Sorghum for Forage			
Year	Acres Harvest (1,000)	Yield (ton)/ (acre)	Prod. (mil. ton)	Farm Value (mil. $)	Acres Harvest	Yield (ton)/ (acre)	Prod. (mil. ton)	Farm Value (mil.$)
		(4)/(2)				(8)/(6)		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1965	56.0	8.5	0.476	3.336	89.6	2.8	0.253	2.934
1964	38.0	5.2	0.199	1.473	74.0	1.4	0.106	1.639
1963	52.0	9.6	0.500	3.247	63.5	3.0	0.190	1.921
1962	56.0	10.4	0.585	3.858	70.5	2.7	0.187	1.723
1961	60.0	9.7	0.581	4.815	61.0	2.6	0.156	1.697
1960	51.0	5.9	0.301	2.771	83.0	1.9	0.156	1.83
1959	35.0	6.7	0.235	1.572	62.0	2.0	0.124	1.168
1958	27.0	8.3	0.224	1.144	53.0	3.0	0.159	1.116
1957	78.0	6.9	0.537	3.332	97.0	1.9	0.182	1.458
1956	38.8	3.6	0.140	1.840	224.5	0.7	0.161	2.941
1955	47.1	2.7	0.126	1.330	250.2	0.8	0.198	3.011
1954	53.9	5.3	0.285	2.707	105.7	1.4	0.151	2.088
1953	50.8	4.8	0.244	2.339	134.3	1.6	0.209	2.842
1952	29.2	4.5	0.133	1.434	107.6	1.5	0.160	3.513
1951	39.1	6.7	0.262	2.327	130.8	1.9	0.253	3.112
1950	14.6	7.8	0.099	0.734	112.7	1.9	0.215	2.105
1949	16.4	6.8	0.110	0.718	102.1	2.1	0.211	2.006
1948	8.7	5.0	0.045	0.326	114.9	1.4	0.165	2.012
1947	8.1	3.9	0.032	0.259	125.1	1.4	0.171	2.395
1946	4.8	3.8	0.018	0.130	162.1	1.3	0.205	2.773
1945	10.3	4.1	0.042	0.243	155.5	1.4	0.225	1.915
1944	15.4	5.6	0.086	0.481	192.1	2.1	0.398	2.748
1943	9.5	3.2	0.030	0.030	171.2	1.1	0.196	2.465

[a]Source: Kansas State Board of Agriculture, Farm Fact, Topeka, Kansas 1943-1965.

TABLE 32. -- Statistics of cattle on farms, Northwestern Kansas, 1943-1965.[a] (Based on Jan. 1)

Year	Cattle On Farm[b]			
	Number	Farm Value (million $)	Price (3)/(2)	Price Index
(1)	(2)	(3)	(4)	(5)
1965	299,600	29.960	100	1.7428
1964	376,700	44.074	117	2.0454
1963	356,000	48.772	137	2.3951
1962	324,000	42.120	130	2.2727
1961	281,000	34.563	123	2.1503
1960	270,000	32.940	122	2.1328
1959	273,000	38.766	142	2.4825
1958	233,000	26.795	115	2.0104
1957	190,000	14.250	75	1.3111
1956	235,000	17.191	73	1.1789
1955	282,700	22.616	80	1.3986
1954	270,200	20.535	75	1.318
1953	272,510	26.979	99	1.7307
1952	257,650	42.512	165	2.8846
1951	213,480	32.675	153	2.6758
1950	210,500	22.524	107	1.8706
1949	202,000	23.230	115	2.0104
1948	195,700	20.157	103	1.8006
1947	205,500	16.029	78	1.3636
1946	230,500	14.060	61	1.0663
1945	238,700	12.412	52	0.9090
1944	179,380	9.687	54	0.9440
1943	174,880	10.003	57	1.0000

[a]Source: Kansas State Board of Agriculture, Farm Facts, Topeka, Kansas, 1943-1965.

[b] This excludes numbers of milk cows.

TABLE 33. -- Production, total digestion nutrition (T.D.N.) for forage and silage in Northwestern Kansas, 1943-1965.

Year	T.D.N.[a] (1,000 ton)	Total Adjusted Acres in Term of Forage[b] (1,000 acre)	Yield (ton/acre) (2)/(3)	Price[c] ($/ton)	Price Index[d]
(1)	(2)	(3)	(4)	(5)	(6)
1965	187.49	164.30	1.14	33.44	1.1722
1964	78.35	124.69	0.63	39.71	1.3922
1963	162.48	132.87	1.22	31.81	1.1151
1962	174.12	145.20	1.20	32.17	1.1277
1961	159.01	141.04	1.13	40.95	1.4357
1960	116.73	151.03	0.77	39.45	1.3832
1959	92.27	108.69	0.85	26.69	0.0411
1958	106.64	89.02	1.20	21.20	0.7433
1957	164.60	201.05	0.82	29.10	1.0202
1956	94.45	276.26	0.34	50.62	1.7747
1955	109.21	313.03	0.35	39.75	1.3947
1954	111.91	176.60	0.63	42.79	1.5003
1953	132.12	202.07	0.65	39.21	1.3748
1952	93.17	146.55	0.64	53.10	1.8616
1951	154.58	182.97	0.85	35.19	1.2337
1950	112.80	132.23	0.85	25.17	0.8824
1949	112.89	123.88	0.91	24.13	0.8461
1948	81.91	126.51	0.65	28.54	1.0005
1947	82.66	160.25	0.52	32.12	1.1260
1946	96.21	167.48	0.57	30.17	1.0579
1945	108.82	169.25	0.64	19.82	0.6949
1944	194.24	212.65	0.91	16.62	0.5827
1943	93.57	183.92	0.51	28.52	1.0000

[a]For computational procedures see p.19.

[b]For computational procedures see p.19.

[c]Total farm value of forage and silage (col. 5 and col. 9 in Table 31) divided by the amount of T.D.N.

[d]For computational procedures see p.24.

APPENDIX B Fitting a Trend to Data Containing Weather Cycle

Fitting a Trend to Data Containing Weather Cycle

Problems of using trend removed and trend included in economic analysis has been previously discussed.[1] The discussion here is to justify that the trend estimated by moving average, least squares, or the composite of the two approaches, does not provide a precise measure of technological improvements or actual trend, but it can serve as a crude approximation of the technological improvements or actual trend.

Table 34 and 35 are the hypothetical data designed to demonstrate how the humber of cycles and length period chosen for a moving average affect the estimation of the actual trend by the least squares, the moving average method, or the composite of the two approaches.

It is assumed that the weather cyclical effects are systematic and oscillatory, and it is also assumed that there is a constant technological effect (line B in Fig. 10 and line B' in Figure 11) and no interaction between technology and weather is considered. The deviation from the technological improvement is regarded as the weather effect. Then, two cases could be considered.

Case I: The cyclical movement consists of complete cycles (see

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[1] Wold, Herman, and Jureen, Lars, *op. cit.*, pp. 240-241.

the hypothetical data of Table 34 and Figure 10 and the cycles begin an uprising.

In this case, the estimated slope of the linear trend is negative (line C) which is different from the hypothetical constant slope (line B). Thus overestimates or underestimated the estimates of the technological and weather effects depending on the convex and concave of the cycles as shown on Fig. 10.

However, in the case of the moving average method, a 8-year moving average (line D) exactly estimates the hypothetical technology (line B). But, in the case of 10-year moving average (line E), the "Slutzky" effect occurs. As the selected moving period moves further away from the actual cycle period, 8 years, the "Slutzky" effects become larger. The importance of selecting the proper moving period is apparent.

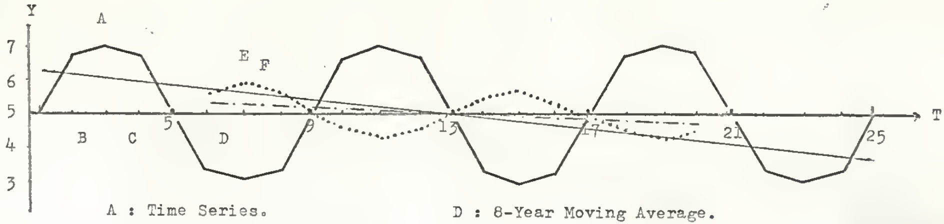
Line F, fitting a linear trend line to the 10-year moving average, also have the same effect as the above. But, the deviation of line F from the hypothetical technology (line B), is less than line C does, which is estimated by the least squares method.

<u>Case II</u>: The cyclical movement consists of incomplete cycles (see the hypothetical data of Table 35 and Fig. 11; and cycles begin with an uprising.. In this case, the estimated slope, the linear trend (line C') and fitting a linear trend line to the 10-year moving average (line F') is nearly zero but are not identical to the hypothetical technology line, (line B'). Line C' slightly deviates from Line B' as compared with line F'.

The 10-year moving average (line F') is also subject to

"Slutzky" effects, whereas the 8-year moving average (line D') is identical to the hypothetical technology (line B').

The number of cycles obviously affect the estimates of technological effect as shown in Fig. 10 and Fig. 11. As the pairs of cycles become fewer, the extent of the overestimates and underestimates by the least squares and the moving average method become greater as shown in Fig. 12.



A : Time Series.

B : Hypothetical Technology.

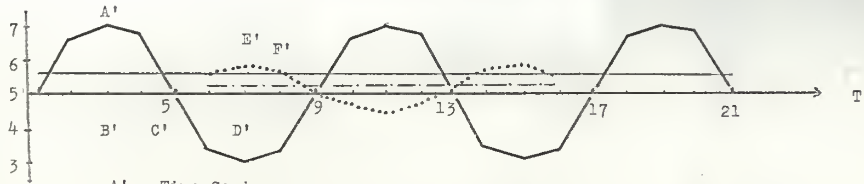
C : Linear Trend.

D : 8-Year Moving Average.

E : 10-Year Moving Average.

F : Fitting a Linear Trend to the 10-Year Moving Average(Y = 5.20 - 0.26 T).

Fig. 10 (Corresponding to Table 39)



A' : Time Series.

B' : Hypothetical Technology.

C' : Linear Trend.

D' : 8-Year Moving Average.

E' : 10-Year Moving Average.

F' : Fitting a Linear Trend to the 10-Year Moving Average.

Fig. 11 (Corresponding to Table 40)

TABLE 34. -- Hypothetical data of cyclical movement

T	1	2	3	4	5	6	7	8	9	10	11	12	13
Y	5.0	6.7	7.0	6.7	5.0	3.3	3.0	3.3	5.0	6.7	7.0	6.7	5.0
T	14	15	16	17	18	19	20	21	22	23	24		
Y	3.3	3.0	3.3	5.0	6.7	7.0	6.7	5.0	3.3	3.0	3.3		

TABLE 35. -- Hypothetical data of cyclical movement

T	1	2	3	4	5	6	7	8	9	10	11	12	13
Y	5.0	6.7	7.0	6.7	5.0	3.3	3.0	3.3	5.0	6.7	7.0	6.7	5.0
T	14	15	16	17	18	19	20						
Y	3.3	3.0	3.3	5.0	6.7	7.0	6.7						

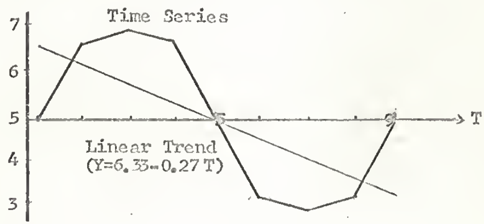


Fig. 12

APPENDIX C

The following manipulations are to demonstrate that the substraction of a constant value from the dependent variable will not affect the regression coefficient. Suppose,

$Y_1 = f(X) = p + q X$, where Y_1 is got from $(Y - Bt)$,

in the equation $Y = A + Bt$ and

$Y_2 = f(X) = p' + q' X$, where Y_2 is from $(Y - A - Bt)$.

i.e.

$$Y_1 = p + q X \text{ . ------------------(i)}$$

$$Y_2 = (Y_1 - A) = p' + q' X \text{ . ------(ii)}$$

The expectation and variance of Eq. (i) and Eq. (ii) could be computed as following:[1]

$$E(Y_1) = E(p + qX) = p + q\,E(X). \text{ ----(iii)}$$

$$V(Y_1) = V(p + qX) = q^2\,V(X). \text{ -------(iv)}$$

$$\begin{aligned} E(Y_2) &= E(Y_1 - A) = E(p' + q'X) \\ &= E(Y_1) - A = q'\,E(X) + p'. \text{ --(v)} \end{aligned}$$

---

[1]For the characteristics of expectation and variance see Yamane, Taro, Mathematics for Economist, Prentice-Hall, Inc., 1962, pp. 414-417.

$$V(Y_2) = V(Y_1 - A) = V(p' + q'X)$$

$$= V(Y_1) = q'^2\, V(X). \text{ --------(vi)}$$

From Eq. (vi), $V(Y_1) = V(Y_2)$. So $q^2\, V(X)$, i.e. $q=q'$.

From Eq. (v), getting:

$E(Y_1) - A = p' + q'\, E(X)$,

also, from Eq. (iii) and Eq. (v), getting:

$p + q\, E(X) - A = p' + q'\, E(X)$.

Since $q = q'$, so $p - A = p'$.

Therefore, Eq. (ii) can be rewritten as

$$Y_2 = (p - A) + q\, X. \text{ -----------------(vii)}$$

Comparing the regression coefficient between Eq. (i) and Eq. (vii), it remains the same. The difference between Y_1 and Y_2 are only the constant term, A.

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THE INFLUENCE OF WEATHER ON CROP YIELDS
AND FARM INCOME IN NORTHWESTERN
KANSAS

by

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The main objective of this study is to estimate the impact of weather on crop yield and farm income from cash crops during the period 1932-1965, and on cattle number and farm value of cattle reported each year on January 1 during the period 1943-1965 in Northwestern Kansas.

A multiple quadratic regression model and recursive model are used in this study. Several variables, such as time, weather and various price indices are included in the estimating equations. The influence of technology on crop yield is estimated by adjust- original data for a linear trend computed from the results of 11-13 years moving average; to estimate the same influence on farm income from cash crops and on yield of total digestible nutrients (T.D.N.) from forage and silage crops, a time variable is included as an independent variable. Weather variables are expressed in terms of Palmer's monthly drought severity index and monthly moisture departure. Prices are computed from reported farm income and production, and price indices are constructed by using Laspeyre's formula.

Results indicate that equations used are reasonable estimates of the impact of weather on agricultural production and farm income, and that Palmer's indices are reasonable good measures of the weather phenomenon in northwest Kansas.

All the equations reported give high coefficients of determination, low standard errors, and T values significant at the 1%, 5% or 10% levels with few exceptions. Conclusions from this study are:

(1) The heading season is the most important period in regard

to weather's effect on crop yield;

(2) Of all crops considered, corn is the most sensitive to weather variation;

(3) The number of cattle on a farm is less sensitive to weather variation than crop production. Fluctuation in cattle number are determinated partly by price level and partly by feed production.

The influence of weather on crop yield, farm income from cash crops for the period 1932-1965, and on number of cattle on hand January 1 of each year and farm value is estimated by, (1) calculating the difference between the reported and the estimated value if weather were normal for each year and then (2) summing the annual differences for the period studied. If the favorable weather offsets the adverse effects of weather, the sum would be zero. Normal weather is defined as having a drought severity index of zero. The calculated effects of weather are as follows:

(1) Dry land yield, 1932-1965:

Wheat yield	Corn yield	Grain sorghum yield	Farm income from cash crops
-0.32 bu/acre	-2.65 bu/acre	+ 1.72 bu/acre	-0.264 million $

(2) T.D.N. number and farm value of cattle, 1943-1965,

Total T.D.N.	Number of cattle	Farm value of cattle
5,720 tons	- 2,068 heads	-0.264 million $

The negative sign for wheat, corn, farm income from cash crops, number and farm value of cattle on farms January 1 of each

year indicates that adverse weather conditions during some years had a greater effect on yield and farm income than did favorable weather.